HIGHWAY ENGINEERING

ARTHUR H. BLANCHARD
AND
HENRY B. DROWNE

TEXT-BOOK

ON

HIGHWAY ENGINEERING

BY

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PREFACE

THE science and art of highway engineering have, during the past decade, rapidly developed along various lines. Within recent years our foremost national engineering societies have manifested marked interest in this branch of engineering, not only through the medium of the presentation of papers, but also by the appointment of Special Committees; for instance, in the American Society of Civil Engineers, there is found a Special Committee on the "Use of Bituminous Materials in Road Construction"; in the American Society for Testing Materials, Special Committees on "Bituminous Materials," "Nomenclature of Bituminous Materials," and "Non-Bituminous Road Materials"; while in the American Society for Municipal Improvements and the Association for the Standardizing of Paving Specifications there are Committees on each of the various types of roads and pavements used in current practice. In addition to the Association Internationale Permanente des Congrès de la Route the following national associations have been founded during recent years to promote the development of highway engineering and the construction and maintenance of "Good Roads": The National Highways Association, the American Road Builders' Association, and the American Highways Association.

The arrangement of the subject-matter given in this book is based largely on lectures that have been prepared by the authors for their various classes, both undergraduate and graduate, and upon their practice as highway engineers in the United States, Canada, and Europe. The book has been written primarily from the standpoint of the instructor and the student; giving, first, the logical order and arrangement of the subject-matter, and second, sufficient detail to thoroughly acquaint the student with the

principles and practice of modern highway engineering. At the same time, however, this book is sufficiently broad in its scope and content with reference to materials, construction, maintenance, specifications and cost data to serve as a comprehensive reference-book upon the subject of highway engineering for the experienced engineer.

It will be seen from the table of contents that all phases of the subject of modern highway engineering are treated. Several chapters will be found that are somewhat of an innovation in books on roads and pavements, as, for example, the chapters on "Preliminary Investigations," "Surveying and Mapping," "Design," "Bituminous Materials," "Dust Prevention by the Use of Palliatives," "Bituminous Surfaces," "Bituminous Macadam Pavements," "Bituminous Concrete Pavements," "Concrete Pavements," and "Economics, Administration, and Legislation." Two hundred and forty-two pages have been devoted to the subject of bituminous materials and their use in the construction and maintenance of roads and pavements.

The writings of eminent engineers and chemists have been drawn upon in order to transmit directly to the reader the views of experts on special subjects. Standard specifications and reports of national societies have been liberally quoted in order that the opinions expressed may be, as far as practicable, representative of the practice throughout the United States rather than that of an individual or a given locality.

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A. H. B.
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HIGHWAY ENGINEERING

CHAPTER I

HISTORICAL REVIEW

It is the purpose of this chapter to give a broad general review of the development of the art and science of highway building from the earliest times to about A.D. 1840. Many of the various forms of modern pavements were not introduced until after this date. It is believed, since the later developments are intimately connected with the details of construction of roads and pavements, that the historical review relative to each type will be of greater value, if it is included in the chapter to which it specifically refers.

Ancient Highways of the Eastern Hemisphere. The economic value of roads in its broadest sense was not appreciated as much by the ancient races as it is today. The primary object of the roads built by them was to facilitate the movements of troops rather than for the development of commercial and social welfare. The nations which were most active commercially, in fact, the leaders as far as the exploitation of agricultural pursuits was concerned, were the Phœnicians, the Egyptians, and the Carthaginians. None of these powers had an extended system of roads, their commerce being entirely transacted by means of ships.

History previous to 1900 B.C. is rather vague concerning the subject of highways. Herodotus tells of a road which was constructed about 4000 B.C. and over which materials of construction used in building the pyramids were supposed to have been hauled. Although Biblical history mentions in several instances that there were public highways, the first roads of which there is any authentic record are those in the Assyrian Empire,

built about 1900 B.C. These roads radiated from Babylon, and the remains of one can still be seen today between Bagdad and Ispahan. This road, as well as the oldest bridge on record of any importance, which is that over the River Euphrates near Babylon, were built about the same time during the reign of Queen Semiramis.

Early Grecian Highways. History is not very definite as to the methods of construction of the roads of ancient Greece. Many of these roads were built as approaches to religious temples. One of the principal roads led from Athens to Eleusis, and served as a means of communication with Peloponnesus, with Thebes, with Phocis, and the greater part of the North. The Greeks, according to some authorities, were not as attentive to drainage in connection with the construction of their roads as were the Romans. They paved their roads with large square blocks of stone instead of polygonal blocks. The royal roads of Greece were under the authority of the Athenian Senate, which levied taxes for the maintenance of the roads, whereas in some of the largest cities such as Thebes, the care of the streets was intrusted to a person of high rank.

Early Roman Highways. According to Isadore de Seville, who lived in A.D. 700, the Carthaginians were the first to build paved roads. Their methods were later copied by the Romans. Carthage flourished from about 600 B.C. to 146 B.C., at which time this empire was destroyed by the Romans. The Romans built roads on a more extensive scale than any of the other nations. Road building was a state policy in the Roman Empire. Gautier says that the Romans divided their roads into several classes as follows: royal roads, vicinal roads, and private roads. The royal roads included the main military roads which traversed all of Europe and the northern part of Africa. The vicinal roads connected the royal roads with the towns or cities. The private roads connected the royal roads or vicinal roads with some particular locality other than a town or city. By means of this system of roads the whole of the Roman Empire could be readily traversed. Soldiers were able to travel as much as twenty miles a day over these roads.

FIG. 1. Appian Way Showing the Surface Paved with Large Stones.

During the reign of the kings, the Roman roads were doubtless constructed of the natural soil without paving. In the year 311 B.C. the censor Appius Claudius commenced the construction of the first paved road, which led from Rome to Capua. This road was named Via Appia (Appian Way), and was later extended and improved by Trajan. This marked the beginning of the construction of Rome's remarkable system of highways. During the next century, Rome continued to flourish, and since the roads were an absolute necessity to the movements of the troops to the various provinces, the construction of roads increased to such an extent that at the end of 200 B.C. the total system comprised about 48,500 miles. Many of the main roads were built under the auspices of different rulers and bear their names. Among these roads might be mentioned the Appian, Aurelian, Flaminian, and Domitian Ways. Twenty-nine of these roads led to the capital. During the reign of Trajan the Roman Empire reached its greatest magnitude, comprising Italy, Britain, Gaul, Spain, Western Germany, part of Asia Minor and Arabia, and including the whole of the northern part of Africa, and the islands in the Mediterranean.

It is evident in examining the old Roman roads, very clear traces of which appear in many of the European countries, that directness of line between any two points was a prime object. A straight line was attained many times in spite of the natural difficulties which had to be overcome. Tunnels, bridges, and retaining walls remain as monuments to their engineering skill. The Flaminian Way in crossing the Apennines passes through a tunnel about one thousand feet long; the Appian Way near Ariccia for a length of about seven hundred and fifty feet is constructed on a viaduct, the retaining walls of which have a mean height of 43 feet, while the viaduct contains three arch spans which serve as a waterway. In low and level land the roads were elevated to a considerable height above the adjoining ground.

Certain of the great military Roman roads were from 36 to 40 feet wide. The middle part, 12 to 16 feet in width, was generally paved or surfaced with some suitable material. This

Fig. 2. Appian Way Showing Gravel Surface.

part of the road is supposed to have been used by the infantry. At either side of the middle portion was built a raised path about two feet wide which may have been for the officers to walk on. Beyond these paths on either side was a width of about eight feet which was supposed to have been used by the cavalry. The breadth of the vicinal roads was fixed by the law of the "Twelve Tables" at 8 feet.

In constructing these roads two parallel furrows defining the width of the road were made and the soil between these furrows was removed to such a depth that a firm and solid foundation was obtained. Sometimes when the soil continued to be of a soft nature, it was made more compact by driving small piles into it. This trench was then filled up to a certain height with sand which was firmly compacted. Upon this sand-bed four successive layers of masonry were built as follows:

1. The Statumen, formed of large stones laid flat in courses and bonded together with mortar or clay. This layer was from 10 to 20 inches thick.

2. The Rudus, about eight inches thick, composed of rubble masonry.

3 The Nucleus, built of masonry similar to concrete, having a thickness of 10 inches, and often composed of fragments of pottery and brick-bats.

4. The Summa Crusta, formed of very hard materials bonded together with a lime mortar, thus possessing great solidity. On many of the military roads large stones, bedded in the Nucleus, were used for this layer, while on other roads small stones mixed with mortar were employed.

The total thickness of the four courses was about four feet. All of the roads, however, were not constructed according to this standard. Some of the roads that were originally built of sand or gravel were later surfaced with stones of variable dimensions. The Appian Way between Rome and Brindisi for a length of about five hundred miles was surfaced with large stones, cut into irregular shapes, bedded very carefully in mortar, and laid in some cases with very close joints. These stones are 3, 4, and 5 feet square, and were, according to some authorities,

transported more than one hundred miles for use in this road. In many places on the Domitian Way the surface was paved with square blocks of marble. In others, the stones were brought from the fields and laid in mortar. Between Nîmes and Beaucaire, where the Roman road has been found to be intact in places, it was paved with dressed stones about seven inches thick. Excavations have shown in some cases the Statumen to have been replaced by broken stones of variable size. In other places the Statumen was replaced by a layer of compacted earth, the Rudus consisted of a bed of lime mortar, and a layer of broken stone replaced the Nucleus. Archæologists have found that old Roman streets within the cities of Pompeii and Herculaneum were paved with large blocks of lava. They have also unearthed some paved streets in which the blocks of a similar size to those used today were laid on a mortar bed.

It would be extremely interesting to know the reasons which led to the adoption of the different types of construction since, based upon our present-day knowledge, there was no need for such massive work. Without doubt, the availability of the materials had a great deal to do with the use of different sized stones and arrangement of courses. It is not difficult to imagine that the desire of the rulers to leave behind some substantial monument of their reign led to the use of some of the methods adopted. The traffic of those times certainly was not such as to warrant the construction of roads four feet thick. Chariots and carts on two or four wheels, having a width of about five feet, were the principal types of vehicles used. Expense was probably of secondary importance, since a large part of the work was accomplished by captives or by the armies. If the item of cost had been a serious consideration, some of the methods would probably have never been used.

The care of the roads was intrusted to a person of high rank. The office of Superintendent of Highways or Curator Viarum, as it was then called, was one of great dignity and honor. Julius Cæsar was the first of high rank to occupy this office, and after his occupancy the office was rarely conferred upon any but

men of consular dignity. Due to the fact that the roads played such an important part in the development of the Roman Empire, it is not surprising that the memories of Cæsar Augustus, Vespasian, Trajan, and Domitian were honored by the erection of one or more triumphal arches to each at the order of the Roman Senate on account of their support and activities in the building up of the roads of the Empire.

Early French Highways. About the middle of the year A.D. 300 the wonderful system of roads, built up by the Romans in Gaul, was abandoned due to the Barbarian invasion. In 395 the Roman Empire was divided into two parts, the Eastern and the Western Empires. The Western Empire was finally destroyed in 476, and at its downfall road building practically ceased. Since the small amount of commercial traffic that was carried on was accomplished by pack-animals the highways outside the large cities became in time no better than bridle-paths. No care was taken of them, and the borders, as well as the roadway itself, became covered with small trees and bushes.

During the reign of King Charlemagne, or from 771 to 814, some activity was again shown in building highways, necessitated by his various military expeditions. The work was carried out mostly by the armies or by the people whom he vanquished. It was about this time, or 950, that the streets of Cordova, Spain, were supposed to have been paved. After the reign of Charlemagne, and up to A.D. 1100, conditions grew worse. In France, the feudal régime was inaugurated, and kingly rights were assumed by the dukes, counts, and other titled personages who set themselves up as leaders of their districts. The whole nation was disturbed by the internal wars resulting from the disputes of these feudal chiefs. It was during this period that the roads perhaps suffered the most, since at times they were torn up and destroyed as a matter of defence in these petty wars. The social state was such in the Middle Ages that the use of a road as a means of communication was practically abandoned. It was not safe for any one to travel since both life and property were at stake. Where travel was possible the head of each fief demanded toll of the persons using

the road, the money being used for his own private enterprises. Since the head of the fief had absolute and final authority in his particular district, the tolls were heavy and an extreme hardship to those who had to pay them. From 1100 to 1200 the only road construction undertaken comprised the opening of some of the old roads incidental to the movements of troops in the Wars of the Crusades. The deplorable conditions as outlined above continued in France until the middle of the thirteenth century, at which time a few of the roads leading from Paris to the feudal provinces in the near vicinity were improved. This work was generally done under the direction of the province chiefs, and the paving was accomplished in a very primitive manner. The streets in the city of Paris were positively filthy early in the thirteenth century. On good authority it is stated that King Philip Augustus was so disturbed at the stench, when he opened a window one day in his palace, that he ordered all of the streets of the city to be paved with hard and solid stone. That this improvement was not demanded by the character of the traffic is substantiated by the fact that it was not until about 1300 that carriages, the use of which had almost entirely disappeared, again began to come into vogue. Under Louis XI. a postal service was established in France, about 1464. In spite, however, of various edicts issued by royal proclamation from this time up to 1600, the feudal system and the administrative organization of the government were such that the revenues which should have been spent in maintaining the roads were diverted to other channels. Roads of secondary importance were not improved at all, and the main highways, except in the vicinity of large cities, were not practicable for use as carriageways.

In 1661, Colbert, who was Minister of Finance of France at that time, did much to try and bring about a change in conditions, but in spite of his far-sighted policies with regard to the construction and maintenance of highways, no material progress was made in developing the French system up to 1700, with the exception of the construction of a few roads near Paris, among which were those of Orléans and Versailles through Sèvres,

The construction and maintenance of the French roads for a long time had been generally carried out by means of the "corvée," which was a system of compulsory labor. M. Turgot, a minister of France, recognized the injustice of this system and suggested several reforms both as to the "corvée," and the feudal systems. Although Turgot was bitterly opposed he succeeded in bringing about the general abolishment of the "corvée," in 1776. He was supported and defended by King Louis XVI. until Marie Antoinette took part against her spouse. Turgot was forced to resign in 1777, and but for the king would have been imprisoned in the Bastille.

Due to the fact that Turgot had accomplished the abandonment of the "corvée," it became necessary to find some method of constructing the highways at a greatly reduced cost. This problem was successfully overcome by Pierre Marie Jerome Tresaguet, who at this time was chief engineer of the District of Limoges, France. It was due to his efforts and skill as an engineer that the first steps toward modern and scientific road-building were taken. Tresaguet's mode of constructing roads, as described by himself in 1764, and adopted generally in France in 1775, was as follows:

"The bottom of the foundation is to be made parallel to the surface of the road. The first bed on the foundation is to be placed on edge, and not on the flat, in the form of a rough pavement, and consolidated by beating with a large hammer, but it is unnecessary that the stones should be even one with another. The second bed is to be likewise arranged by hand, layer by layer, and beaten and broken coarsely with a large hammer, so that the stones may wedge together and no empty space may remain. The last bed, three inches in thickness, is to be broken to about the size of a walnut with a small hammer, on one side on a sort of anvil, and thrown upon the road with a shovel to form the curved surface. Great attention must be given to choose the hardest stone for the last bed, even if one is obliged to go to more distant quarries than those which furnish stone for the body of the road; the solidity of the road depending on this latter bed, one cannot be too scrupulous as to the quality of

materials which are used for it." He is also credited with being the first to propose a system of maintenance.

The Revolution naturally retarded the development of the national road system of France. During the period from 1804 to 1814, while Napoleon Bonaparte was Emperor of France, road-building gained a new stimulus. One result was the establishment of the remarkable system of national roads. It is very probable that Napoleon's various military expeditions into the surrounding countries furnished the motive for the construction of these roads. About this time the Department of Roads and Bridges was created, which to the present has had the direction of the road construction in this country.

Early British Highways. Conditions in Great Britain after the fall of Rome and during the Dark Ages were similar to those in France. The roads were allowed to get into a most deplorable state. An act passed in England in 1285 directed that all bushes and trees should be cut down for a distance of 200 feet on either side of the highway. The undergrowth had become so thick along the highways that it afforded an excellent hiding-place for robbers, which led to the improvement sought by the above act.

The first act for paving the streets of London was passed in 1532, and apparently for a somewhat similar reason as was the case in Paris. In the statute the streets were described as "very foul, and full of pits and sloughs, so as to be mighty perillous and noyous, as well for all the king's subjects on horseback, as on foot with carriages." Large irregular boulders, 6 to 9 inches deep, were first used. Due to the wide joints between the stones, the irregular shapes, and the unstable foundations, the surface soon became very uneven and exceedingly rough.

In 1555 a law was passed providing that surveyors should be elected to take charge of the roads in their parishes and empowering them to exact four days' work each year on the roads from every parishioner. In 1562, these supervisors were empowered to turn any water courses or springs from the highways to ditches on the adjoining ground, and were further empowered to repair a road with material taken from any source with or

without the owner's permission. The first turnpike act was passed in 1663. Little was done to the roads, however, and although they were passable, they were in an extremely poor state of repair. Ruts and mud-holes 4 feet in depth were of frequent occurrence. By 1809, due to the fact that the turnpike system had been extended, there were over one thousand turnpike trusts to keep the roads in repair. This supervision, however, was restricted, more or less, to small communities, and it was not until McAdam took charge of the roads that any systematic improvement of the roads was accomplished.

John Loudon McAdam returned from America to Scotland in 1783, and was commissioner and trustee of roads in Scotland from this time until 1798. Minutes of evidence given by him in 1823 said: "In 1798 I began to make it a sort of business. Without saying to any one what my object was, I travelled all over the country in different parts, . . . as often as I had leisure and convenience down to the time I took charge of the Bristol Roads, or about the latter end of 1815. I found that the roads were extremely bad in all parts of Great Britain as far back as 1798, and that very little improvement took place in them between then and the year 1815, which I attributed to the ignorance of the persons who had charge of them, the ignorance of the surveyors, the total want of science. I found the materials so applied that the roads were all loose, and carriages, instead of passing over the roads ploughed them; that was the general fault of the roads; and the loose state of the roads, I apprehend, was owing to the bad selection of materials, the bad preparation, and the unskillful laying of them." McAdam was the first to recommend the construction of a broken stone surface of small-sized broken stone without any foundation other than that furnished by the earth road-bed. Associated with the period in which McAdam demonstrated the success of his method of construction are the names of several other engineers, namely, Telford, Walker, and Edgeworth, all of whom helped to further perfect the principles laid down by McAdam and Tresaguet.

The boulder pavements first used in London were later

succeeded by a crude type of block pavement composed of blocks measuring 6 or 8 inches across the surface. The blocks were very irregular in shape, and as no stable foundation was provided, these pavements were no improvement on those first constructed. It was not until 1824 that the deficiencies of this system were pointed out by Telford. At this time he recommended using paving stones of granite, cut square on all sides, so as to furnish a close joint and having a base the same dimension as the top surface. The dimensions of the stones were to be as follows:

Class of Street	Width Ins.	Depth Ins.	Length Ins.
For streets of the 1st class........	6 to 7½	10	11 to 13
For streets of the 2d class........	5 " 7	9	9 " 12
For streets of the 3d class........	4½ " 6	7 to 8	7 " 11

He also recommended constructing the pavement on a broken stone foundation 12 inches deep.

In other parts of Europe, from the time of Rome's downfall to about the beginning of the eighteenth century, the history of road-building is a repetition, to a more or less extent, of the developments during the same period in France and England. It was not until after the influential work of Tresaguet, McAdam, Telford, and others had been accomplished that any marked progress in the development and construction of roads throughout Europe took place.

Early American Highways. The first highways constructed in America of which there is record are those supposed to have been built by the ancient Incas of Peru. Gautier, in describing one of these roads which led from Quito to Cuzco, said the road had a width of 25 feet, and was paved in some places, where it was necessary, with large stones 10 feet square. The roadsides were bordered with trees and supported in places by retaining walls.

The development of highways in North America was much slower than in other countries. The United States was settled

by various colonists, principally from England, at a time when the road situation in England was particularly bad, hence the value of improved highways was not appreciated. The colonies were established along the eastern coast at widely separated points. Most of the communication between the different settlements was carried on by water. Because the colonists were kept active protecting themselves from the Indians and on account of lack of money, they did very little in the way of laying out roads outside of the settlements except to clear out rough trails. It is known that some paving was attempted within the settlements at a very early date. The streets of Boston, Mass., were paved, probably with cobble-stones, as early as 1663, and records show that a similar form of pavement was introduced in New York at about this same time.

The French first settled in Canada. They took advantage of the various great rivers and lakes on the northern border of the United States and the Mississippi River and its tributaries in establishing a line of settlements west of the Alleghany Mountains. It was evidently the intention of the French to form a cordon of settlements west of those of the English, and to ultimately close in and drive the English from America.

The only connections between the French and English settlements over land were the various trails made by the big game animals or by the Indians. The buffalo seemed to have had a peculiar instinct in picking out the easiest trails. In many instances these trails were followed by the Indians, and with the progress of civilization they became the highways.

The following rules were adopted by the Government of New York in 1664: "The highways to be cleared as followeth, *viz.*, the way to be made clear of standing and lying trees, at least ten feet broad; all stumps and shrubs to be cut close by the ground. The trees to be marked yearly on both sides; sufficient bridges to be made and kept over all marshy, swampy, and difficult dirty places, and whatever else shall be thought more necessary about the highways aforesaid."

The old York road which ran between New York City and Philadelphia was the first important road in the colonies. It

was laid out in 1711. In forcing the French from the Ohio Valley about the middle of the eighteenth century, several military expeditions were sent out from Virginia across the Alleghany Mountains. George Washington was one of the first to lay out a military road over this route in 1754, for the purpose of moving Colonel Fry's army. In 1755, General Braddock, of the English Army, in making a similar expedition against the French, followed somewhat the same route as laid out by Washington. There was very little real progress in road-making until the last quarter of the eighteenth century, when the necessity for more and better roads was met in many cases by the construction of toll roads in various parts of the country. These roads were built and owned by private corporations which exacted payment from those using the road.

The old Lancaster Turnpike, which ran from Philadelphia to Lancaster, Pa., was the first macadam road built in the United States. As originally constructed in 1792, the surface was composed of stones of all sizes thrown together and covered with earth. The roadway became very unsatisfactory, and at a later date it was reconstructed with a macadam surface, no stones being used in the surface that would not go through a 2-inch ring. The success of this type of construction was quickly appreciated, and many of the toll roads constructed up to 1811 were built by this method. By 1811 there were about 4,500 miles of road comprising 317 turnpikes that had been chartered in New York and the New England States. Many of the roads built by private corporations were not a financial success, and whenever abandoned they usually came under the control of the State in which they were located. During the time that toll roads were being built to a large extent, the forced labor system was practically abandoned, but it gradually returned with the decline of the toll roads, and is still in operation in many of the States.

The construction of the Cumberland or National Road by the Government led to some further activity in road-building. This road extended from Washington westward to St. Louis, and was built with a 20-foot width of broken stone, 18 inches

deep at the middle and 12 inches deep at the sides. It was started in 1806, and various appropriations were made for its construction by Congress during a period of over forty years. In certain localities the Cumberland Road was built upon the bed of the road as laid out previously by Washington and Braddock.

Up to 1840 the principal paving used in American cities was cobble-stones. The improvement of highways outside of the cities was retarded for a period of several years beginning with 1837, due to a money stringency. The rapid development of the railroads in this country also served to establish communication between points which otherwise would have been connected by improved highways.

CHAPTER II

PRELIMINARY INVESTIGATIONS

The design and construction of a road or street should never be undertaken without first making a thorough study of existing conditions. Such an investigation carried out in an intelligent manner may not only result in a great saving in the first cost of the work, but also may preclude the use of certain types of construction which otherwise might be adopted. The purpose of making a reconnaissance for a proposed railway is principally to determine several routes, any one of which may later be selected after careful estimates of cost of construction have been made. In other words, a reconnaissance is mainly a study of location in which curvature, grade, and distance are the main points considered. Location is, of course, important in highway work, but there are many other points just as important, full knowledge of which should be obtained in order to enable the engineer to determine on the most economical and efficacious method of construction.

A preliminary investigation should cover the following essential factors: location, foundation, drainage, æsthetics, width, traffic census, and climatic conditions. The investigation should also cover the following details: normal and abnormal speed of various classes of traffic, the nature of horses' shoes and non-skidding devices used, the traffic regulations in force, the probable change in the character and amount of traffic, the topographical and geological structure and features, the condition and character of cross-roads, the character of existing surface, the possible diversion of traffic, the months available for construction, the availability of materials, the methods of street cleaning and maintenance in vogue, the plant equipment, and the character of available labor

As considerable ambiguity exists in regard to the meaning

of the terms highway, road, street, boulevard, and pavement as used by many writers, the following definitions are given in order that the use of these terms in this book may be understood.

Highways are the right of ways devoted to public travel, such as alleys, roads, or streets, including the sidewalks and other public spaces, if such exist.

Roads are highways outside of a city, town, or village. The term also refers specifically to the surfacings of the travelled ways or carriageways, when such surfaces are composed of earth, gravel, broken stone, or similar materials.

Streets are highways in a city, town, or village, including the full width between property lines. Streets, therefore, include the carriageways and sidewalks.

Boulevards are usually wide roads or streets constructed with particular attention to æsthetic details and with extraordinary consideration of pleasure travel.

Pavements are the surfacings of the carriageways or footways, when such surfaces are monolithic with a cement or bituminous binder or are composed of blocks.

Location. There are several essentials of good location which, on making a preliminary investigation relative to a proposed highway, will at once be apparent. It is always desirable to eliminate bad grades as much as possible, and in the location of highways without built up districts many opportunities exist to make a decided improvement from this standpoint. Although generally a reduction in grade may considerably increase the cost of construction, there are instances, even in extremely rough country, where a low rate of grade has been obtained without material increase in the cost, provided the property damages are not excessive. In thickly settled communities it is rarely feasible to depart much from the lines of the old highway, but there is so much undeveloped land in the rural districts, particularly of the United States, that the abandonment of the old highway for the purpose of reducing the grade is often an easy matter. Such a desirable change would be apparent by a preliminary examination of the road. The cost of such a change

could only be determined by making careful estimates. Unfortunately, within the city limits, and particularly the very old cities, it is generally impossible to change grades which would be materially improved if the city were being laid out today. In such a case a report on the grade in a preliminary investigation would simply state the rate of grade and the general effect of the grade from the standpoints of use, surface drainage, etc.

What has been said with regard to the elimination of bad grades applies as well to curves. Sharp curves under modern traffic conditions are undesirable from several standpoints. By a judicious relocation of the highway, which many times may only mean a slight shifting of the line, considerable improvement may be obtained. If such changes are thought desirable, it is advisable to confer with abutting property owners to see if satisfactory terms can be made with regard to property damages. Although it is true that many states have the right of eminent domain, it is not tactful to entirely disregard the wishes of property owners, which sometimes deserve serious consideration.

Foundations. The foundation on which the road is to rest is of the utmost importance, and hence should receive more than a superficial examination. The failure of many highways has been caused by poor foundations or improper drainage. Of course, in localities where highways have been built for a number of years, experience will have shown what may be expected under certain conditions. In new country, however, where no improved highways exist, the only practical way to gain an idea as to the nature of the soil conditions is to dig test pits at frequent intervals along the proposed location and to examine the material encountered. Under certain conditions an old earth road-bed may present a very fair appearance at the time it is observed, but there may be other times of the year when this same piece of road would be nothing more than a veritable mud hole, seemingly without bottom. A change of line to avoid bad foundations may be very apparent. Such information is most useful and is the kind that should be sought after. Much can be learned by careful inquiries.

Drainage. Drainage is so closely allied to foundations that

it is rather difficult to discuss one without considering the other. Those places where the foundations can be improved by subdrainage should be determined as far as possible. There will probably be numerous instances where water at the sides of the highway will indicate the presence of ground water in the vicinity that can easily be removed by proper drainage. Much may be learned with regard to the surface drainage also. The engineer in making his investigation may not be on the highway at a time to note the worst conditions. For instance, water may flow over the street or road at certain points in great storms; there may have been occasions when the middle of the highway has been gullied out by the water to a great depth; some places that appear to be useless waterways may flow full at certain seasons of the year. Information relative to the above points is extremely helpful in making an intelligent design.

Width. There are many cases where the property has encroached on the lines of the highway to such an extent that if the lines are adhered to only a very narrow carriageway could be built. In some places, where the above conditions are apparent, a study of the deeds and old maps in the recorder's office will be sufficient to determine the correct lines. The nature of the traffic will largely determine the necessary width of the carriageway. Provision for the future, however, should be seriously considered, since any locality is liable to grow and hence provisions made for future development may sometimes be of inestimable value. A study of the development of places in the near vicinity, their relationship with each other, and their industries will help in solving the problem. Had some engineers been far-sighted enough, the narrow streets encountered in our principal cities would never have been built and the costly improvements which are being undertaken at the present time to overcome these "mistakes" would never have been necessary.

Local Materials. It has been said that the ideal engineer is the one who will find one dollar sufficient where the ordinary man would spend two. There is no better opportunity to put this into practice than in highway engineering. A thorough knowledge of the materials available in the locality may suggest

some method of construction to be adopted that otherwise would be overlooked. For instance, a locality may be devoid of stone and the cost of importing stone blocks or broken stone may be excessive. In this same place there may be an abundance of clay that would make a first class paving brick. The recommendation that brick should be manufactured and used would be advisable. There may be certain industries in the near vicinity that accumulate a lot of waste material, such as slag, for example. An investigation of this material would show the practicability of its use in construction. The nature of the soil, the location of gravel-pits, sand-pits, ledges, and quarries will be of the greatest assistance in deciding on the type of construction.

Climatic Conditions. The climatic conditions encountered have to be borne in mind in selecting the type of road or pavement best suited for any particular locality. This is especially true in the case of many of the modern bituminous pavements. A wide range of temperature will necessitate the use of a different bituminous material than where the range is not so great. The climatic conditions may be such that it will only be practical to carry on the construction in certain months of the year, or it may be possible in some localities to do work throughout the entire year. The snowfall may be so great and the weather so cold that in some sections the highways will be constantly covered with snow during the entire winter season, in which case the cost of maintenance may be materially reduced.

Maintenance. If a road is to be efficiently maintained some saving in the first cost might be made and the road would still be successful. It is unwise, however, to suggest a cheaper form of surfacing with the expectation of proper maintenance, unless one is thoroughly satisfied that the proper degree of maintenance can be obtained.

Local Environments. The nature of the locality through which the street or road is to pass should be ascertained. For instance, in the vicinity of hospitals or schools it is desirable to have as noiseless and sanitary a pavement as possible. The same quality is appreciated in residential districts. Near docks, on the other hand, the noise feature, although objectionable, is

not of so much consequence. The grade of the highway will also influence the selection of the type of surface. On steep grades taking heavily laden vehicles drawn by horses a surface must be furnished which will provide a firm foothold, and at the same time withstand the wear.

Æsthetics. In highway designing æsthetics is sadly neglected in this country. We do little to beautify our highways, whereas in some of the European countries the sides of the highway are bordered with beautiful trees and parkings, which not only enhance the appearance of the highway, but also make it more comfortable for use. It should be remembered that trees are a valuable asset to any city, and in reconstructing a highway extreme care should be taken not to destroy them. There are places where a slight change of line, grade, or width would preserve trees that otherwise might have to be removed. The purpose for which a highway is to be used should be taken into consideration. For instance, in the case of a proposed park system an investigation might disclose some very beautiful natural surroundings, through which the road should pass. The alignment of the highway in this case should be studied with the idea of changing the natural conditions as little as possible.

The appearance of the finished highway and its relation to the environments should always be kept in mind. Notes should be taken regarding the abutting property and the approaches to the property from the highway. The frontage of many fine country estates along the highway has been marred because no attention has been paid to this detail. Within the cities the investigation should be made particularly thorough, with reference to street intersections. Poorly designed street intersections are an ever present eyesore. Although it is not always possible to design an ideal intersection, at the same time if more preliminary study were given to the application of æsthetic principles to mere detailed design, the ideal would more frequently be attained.

Traffic. One of the most important considerations in a preliminary investigation is that of traffic. The inherent value of statistics relative to traffic on all classes of highways, ob-

tained previous to construction, is recognized by all engineers who are familiar with the problems of modern highway engineering, and who take into careful consideration the economics of construction and maintenance. Some of the fundamental principles involved are contained in the following quotation taken from the 1912 Report of the Special Committee on "Bituminous Materials for Road Construction," of the American Society of Civil Engineers: "Your Committee desires to emphasize the fact that experience has demonstrated the value of traffic censuses taken both preliminary and subsequent to the construction of a highway. The traffic census should be considered one of the most important variable factors in the solution of that important problem, the selection of that type of road or pavement best suited to local conditions considered from both the standpoints of economy and efficiency. In connection with the census returns on any road should be considered the traffic on cross and parallel highways and the effect of improvement of these highways on the traffic of the highways under consideration. It should not be taken for granted that the bald return of a traffic census should be the sole basis of the selection of the type of road or pavement; but it should be considered a guide in estimating the value of the type of construction adopted."

Traffic Classification. Various classifications of the traffic to which the highways are subjected have been proposed from time to time during the past few years, but the methods to be employed in securing a satisfactory traffic census have not been made the subject of extended discussion in the technical press.

The principles underlying the essential elements of any classification of traffic may be stated briefly as follows: (a) differentiation between horse-drawn vehicle traffic and motor-car traffic; (b) a division of each of these classes of traffic into pleasure and commercial traffic; (c) a subdivision of commercial traffic into loaded and unloaded vehicles; (d) the determination of the weight per linear inch of width of tire of all types of commercial traffic, a factor of the utmost importance in the design of the substructure of the road; (e) a subdivision of the

two classes of horse-drawn vehicle traffic dependent upon the number of horses; (f) subdivision of pleasure motor-car traffic upon the basis of weight and speed, since in many instances the greatest damage to an ordinary macadam road is caused by seven-seat touring cars, limousines, or landaulets travelling at speeds of forty to sixty miles per hour; (g) a subdivision of motor-truck traffic upon the basis of weight and speed; (h) provision for extraordinary character of local traffic, for example, in certain localities many saddle horses may use the public road,

FIG. 3. Showing Different Types of Traffic to Which a Road May be Subjected.

in others, traction engines hauling trailers may be common, while in others motor-bus traffic may be a regular and important feature; as a final illustration, special types of commercial traffic such as ice wagons, mill drays, etc., may be influential features.

As an integral part of the requisite investigation preliminary to economical and efficient design other facts relative to traffic should be obtained, as, for example, the direction of the traffic, the portion of the road occupied by various kinds of traffic, the relationship existing between reduced grades incurring increased distance between two points and probable traffic, the kind of shoes worn by the horses at various seasons of the year, the use of non-

skidding devices employed by motorists and the enforced traffic regulations governing the use of the highway, especially with reference to limitations upon speed and loads to be carried.

In connection with the preliminary investigations, an engineer must always consider the change in the character and amount of traffic that is liable to occur after the improvement of a highway. The importance of an estimate of probable traffic cannot be over emphasized. As an example may be cited the marked change in the character of the traffic resulting from the

FIG. 4. A Common Type of Motor Truck.

construction of a bituminous concrete pavement on a trunk line between two towns in Rhode Island. Two trunk lines have been completed between the two towns in question, one of ordinary macadam oiled at intervals during the summer, the other as described above. The route of ordinary macadam is three-fourths of a mile shorter than the new route, but nevertheless the longer one of a total of three miles is the more popular with the motorist for the reasons enumerated: first, less opportunity of meeting horse-drawn vehicle traffic; second, superior road from an æsthetic standpoint; third, better surface. There exist cases where the change in the character of or the unusual in-

crease in traffic after the construction of a highway renders unwarranted the securing of comprehensive traffic data previous to construction. By the careful preliminary investigation of such cases the engineer will be able to determine the method to be employed in order to secure the requisite traffic census data for the design.

Various typical classifications of traffic and other detail relative thereto which have been published will be given, a thorough study of which will furnish some information in connection with local problems.

Courtesy of Buffalo Steam Roller Company.

FIG. 5. An Example of Abnormal Traffic, Roller Drawing Loaded Stone Wagons.

Methods used prior to 1900. French engineers have for a long time realized the importance of taking a traffic census. An abstract * of the report presented to the Second International Road Congress, by A. Moulleé, Chef de la Division des

* See "Highway Engineering as Presented at the Second International Road Congress, 1910," by Blanchard and Drowne.

Routes et Ponts au Ministère des Travaux Publics Paris, is as follows.

"Ten censuses of traffic over the entire country have been undertaken by the Department of Bridges and Roads. The intervals between the taking of these comprehensive data have varied from five to nine years. The first census of national scope was taken in 1844, although previous to that time traffic data had been collected in certain localities. Traffic censuses

Courtesy of the International Motor Company.

Fig. 6. Commercial Motor Trucks Hauling Lumber.

of national character will in the future be undertaken every ten years.

"Previous to the advent of the motor car the categories of traffic noted underwent little change. Five divisions were recognized; first, freight vehicles and those for agricultural purposes when loaded; second, public vehicles for common transport of travellers and luggage; third, empty freight or agricultural carts and private carriages; fourth, unharnessed animals of large size; fifth, light live stock."

In 1873, William Haywood, who was engineer and surveyor to the Commissioner of Sewers to the City of London, made a very extensive report * as to accidents on different types of pavements. It was necessary to obtain the total traffic passing on the streets under observation. Mr. Haywood describes the method he adopted in his report as follows:

"For ascertaining the traffic two men were stationed at each

Courtesy of the International Motor Company.

FIG. 7.—Motor Truck Hauling Broken Stone.

point of observation, and on opposite sides of the way, each man taking the traffic on the side of the road which was nearer to him, and passing in one direction only. The men were employed for three hours at a time, and were then relieved by others for three hours; and there were, therefore, altogether four men employed during the day at each point of observation. Each man

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* See pp. 297 to 317 of "Streets and Highways in Foreign Countries," Vol. 3 of Special Consular Reports, Washington, 1891.

was on duty for six hours daily. The observations were taken from 8 A.M. to 8 P.M., a period of twelve consecutive hours.

"Observations of the main streams of traffic were taken at each selected spot for two consecutive days in a week; and were followed by two other days' observations in the week after, but on different days to those of the preceding week. They were carried on in such order until six days' observations, including every day in the week (Sundays excepted), had been taken at each point. Observations of cross or collateral traffic were also taken sufficiently to enable the effect on the general stream of traffic to be ascertained."

The first traffic census in this country was planned and carried out under the direction of Capt. F. V. Greene in 1885. The traffic was observed on six consecutive days from 7 A.M. to 7 P.M. Night traffic was not counted and no allowance was made for the same. The classification adopted was as follows:

1-horse carriages, empty or loaded 1-horse wagons, empty or light-loaded 1-horse carts, empty	less than 1 ton.
1-horse wagons, heavy loaded 1-horse carts, loaded 2-horse wagons, empty or light-loaded	between 1 and 3 tons.
Wagons and trucks drawn by 2 or more horses, heavy loaded	over 3 tons.

There were several censuses made in the United States and Canada based on this method. It is self-evident that the above classification is not complete enough to cover modern conditions.

Methods used since 1900. Quoting further from the report by A. Moulleé, previously referred to: "Until the census of 1903 this classification was considered sufficient, but the increase in the amount of motor-car traffic necessitated separate classification of this type of vehicle. Five categories are here also recognized; first, motor vehicles with metal tires, which are usually heavily loaded; second, motor cycles; third, vehicles with elastic tires capable of travelling thirty miles an hour and compelled by law to have a registration number attached; fourth, vehicles with elastic tires which cannot attain this speed; fifth, cycles.

Courtesy of the International Motor Company.

FIG. 8. Motor Truck Used for Conveying Building Materials.

"Coefficients of reduction are applied to each division of classification of both groups of traffic so that totals may be expressed in comparable units. The unit adopted is known as a 'collar,' and is described as a traction animal harnessed to a loaded vehicle. The coefficients of reduction employed are given in the following table:

1. Vehicles loaded with produce or merchandise, and public conveyances for travellers	1
2. Empty or private vehicles	½
3. Unharnessed animals	⅓
4. Light live stock	$\frac{1}{30}$
5. Motor cars with metal tires or traction engines	$\frac{\textit{Wt. in tons}}{0.284}$
6. Motor cycle	0.3
7. Motor car with number	3.0
8. Motor car without number	1.0
9. Cycle	0.05

"The tonnage is estimated as the weight transported. It is impossible to weigh on scales all the different types of vehicles, but by means of a sufficiently large number of actual weighings, and information gathered from the principal transport agents, the average weight which a collar of each category on each section of the road draws is ascertained.

"Tonnage is divided into 'useful tonnage' and 'gross tonnage.' The gross tonnage includes everything that is drawn, while the useful tonnage covers only the load carried by the vehicles. The weight of persons was in the earlier census considered as useful tonnage, but, since 1882, this has not been the case.

"The importance of a census of tramway traffic in connection with a census of highway traffic has been recognized for a number of years. The usual method employed is to secure such data from the companies that operate the tramways. It has been recognized that the influence exerted by the tramways on the wear and tear of roads is in no wise a function of the traffic intensity, but that it depends more especially on the position of the rails in the road and the width of the area which remains entirely free beyond the rails for ordinary traffic."

A. N. Johnson, M. Am. Soc. C. E., State Highway Engineer

of Illinois, in 1906, employed a classification of horse-drawn vehicle traffic based on a distinction between the traffic going toward important towns and traffic going from towns, and a subdivision into loaded and unloaded vehicles. A further subdivision of the traffic was based upon the number of horses employed. "In winter the traffic was recorded during the daylight hours, in other seasons of the year from 6 A.M. to 6 P.M. The days were so selected that if the first count came on a Monday, the next would come on Tuesday of the following week, Wednesday of the next week, and so on."

Since the advent of the motor car, traffic classifications have undergone a transformation. One of the most comprehensive which has been noted is the preliminary form proposed by the new Road Board of England. The classification includes the following list of vehicles:

Tramcars (Electric, Steam, or Horse).
Motor Vehicles:
- Ordinary Motor Cars (including cabs).
- Motor Omnibuses.
- Motor Delivery Vans.
- Heavy Motor Lorries.
- Tractors or Traction-Engines (Trailers are to be counted as additional vehicles, *i e.*, a traction-engine with two trailers would be entered as 3).
- Motor Bicycles and Tricycles.
- Any other Motor Vehicles not included in any of the above heads

Horse-Drawn Vehicles:
- Omnibus (including Public Service and Hotel).
- Two-wheeled Vehicles (one horse).
- Two-wheeled Vehicles (two horses, or more).
- Four-wheeled Vehicles (one horse).
- Four-wheeled Vehicles (two horses or more).

Other Traffic:
- Ordinary Bicycles and Tricycles
- Herds of Cattle (if more than five in number) to be entered as one.
- Flock of Sheep and Pigs (if more than five in number) to be entered as one.
- Horses (led or ridden).

In the United States the following classifications have appeared either in reports or in the technical press.

Classification used by the U. S. Office of Public Roads:

Loaded one-horse wagon.
Unloaded one-horse wagon.
Loaded two-horse wagon.
Unloaded two-horse wagon.
Loaded four-horse wagon.
Unloaded four-horse wagon.
One-horse pleasure vehicle.
Two-horse pleasure vehicle.
Motor cycle.
Saddle horse.
Excessively heavy vehicle (such as carry ore, stones, timber, machinery, etc.).
Motor runabout.
Motor touring car.
Loaded motor dray.
Unloaded motor dray.

The directions state that "less than a week's record is unsatisfactory, and it is best that a record should cover as many seasons of the year as possible."

The classification employed by the State Highway Commission of Massachusetts, in 1909, was as follows:

Single horse, light vehicles.
Single horse, heavy vehicles.
Two or more horses, light vehicles.
Two or more horses, heavy vehicles.
Automobiles, touring cars.
Automobiles, runabouts.

In the above classification "light vehicle" was employed to cover buggies, democrat wagons, or any other vehicle which is used for pleasure or light business purposes while the term "heavy vehicle" was used to designate farming wagons, milk wagons, tip carts, grocery or provision wagons, or any other vehicles except autos which are used for carrying heavy loads. The traffic was taken in two-hour periods consecutively from 7 A.M. to 9 P.M. Two sets of observations were made, one covering a week in August, the other a week in October.

In 1909 the New York State Highway Commission had a traffic census taken upon the county highways built by State aid at four different periods. A traffic census was also taken in 1909 on state and county roads which would probably be built in 1910.

The classification adopted was as follows, relative weights being given to different types of traffic:

Class of Traffic	Relative Weight
Horse-Drawn Traffic:	
Horse without vehicle	1
One-horse vehicle, light	2
One-horse vehicle, heavy	3
Two-horse vehicle, light	3
Two-horse vehicle, heavy	4
Three-horse vehicle, heavy	5
Four-horse vehicle, heavy	6
Motor Vehicles:	
Motor cycle	1
Two-passenger car	2
Three-passenger car	3
Four-passenger car	4
Five-passenger car	5
Six-passenger car	6
Seven-passenger car	7
Freight trucks, omnibuses, etc.	10
Miscellaneous:	
Traction engine	15
Two-traction engine	30
Miscellaneous heavy traffic	5 upward

The records were made by multiplying the traffic units by relative weights and noting the two subdivisions, horse and motor.

In a form covering "Data concerning the Use of Bituminous Materials in Road Surfacing," used in connection with the work of the Special Committee of the American Society of Civil Engineers on "Bituminous Materials for Road Construction," the following classification was adopted.

Horse-Drawn Vehicle Traffic:
- One-horse vehicles.
- Two-horse vehicles.
- Three-horse vehicles.
- Four-horse vehicles.
- Five-horse vehicles.
- Six- or more horse vehicles.

Motor Vehicle Traffic:
- Motor cycles.
- Motor runabouts.
- Motor touring cars (four or five seats).
- Motor touring cars (six or seven seats), including limousines or landaulets.
- Motor wagons or drays.

By means of columns a further division of the above classes of traffic is called for under the headings, empty vehicles, loaded vehicles, and passenger vehicles. A column is also provided for an estimate in pounds of the maximum load per inch of tire.

In the new form recently issued in connection with the work of the above Committee covering a "Report on Results of the Use of the Bituminous Materials in Road Construction," two sets of records are called for, one covering the period from November to March, the other from April to October.

The classification adopted by the Rhode Island State Board of Public Roads in 1908 was similar to that just stated, but a further subdivision of the horse-drawn vehicle traffic was recognized, namely, vehicles with iron tires and those with rubber tires.

For purposes of comparison the results of a traffic census should ultimately be reduced and expressed as a certain amount of traffic or under some conditions as so many tons per unit of width per unit of time, since it is obvious that on a wide and a narrow roadway, taking the same number of vehicles for a stated length of time, the surface of the narrower one will in all probability be subjected to a much more concentrated wear. A self-evident desideratum is the comparison of all kinds of traffic reduced to a common basis by weighting or otherwise.

Methods of Taking Traffic. After the classification of the traffic has been adopted, the methods of securing traffic data must be considered from many standpoints before a final decision is reached.

The method selected will be influenced by the amount of time at the disposal of the engineer and the character, amount, and distribution of the traffic to which the highway in question is subjected. In case the location of the highway to be built in a given period is known over a year in advance of construction, a comprehensive plan covering observations throughout the year should be adopted in order to secure complete information. In many instances, however, perhaps only a month will be available in which to make investigations preliminary to design. In either case, it is essential that as complete information as pos-

sible should be secured relative to the nature of the traffic on any given highway before a plan is adopted. As the primary object of any traffic census is to secure data covering both normal and abnormal traffic of all classes, it is essential to incorporate in a plan definite provision for securing the above information rather than to depend upon a haphazard selection of days to furnish the facts. As an illustration of varying local conditions may be cited: exceptional horse-drawn vehicle traffic, consisting of produce wagons, between the hours of midnight and 6 A.M. during certain seasons of the year; market days, fair days, and other special events in connection with which both pleasure and commercial traffic may be excessive; periodical heavy shipments by special industries using the highway in hauling raw material or in shipping the manufactured article; through traffic at certain periods of the day, week, or year as, for example, motor-car traffic between residential communities or summer colonies and cities. After having obtained all the information of this nature it is possible to glean from local sources, the next step is the consideration of the most economical plan to be adopted in order to secure the essential data.

In many cases it is essential to obtain the following: normal winter traffic, normal summer traffic, and abnormal summer motor-car traffic. It should be borne in mind that from the standpoint of the proper design of the highway, it is necessary to know approximately the total yearly traffic, which is a function of both the normal and the abnormal traffic, and also the amount of abnormal traffic of various types at different periods of the year.

Three plans for taking traffic census throughout the year covering the usual conditions will be considered. Two of these plans at once suggest themselves, first, to take the traffic in periods of six or seven consecutive days, and second, to distribute the recording days throughout a given season by starting on a given day of the week, for example a Monday, then take the traffic on the Tuesday of the following week or at an interval of fifteen days, and so on during the season. The merits of the two schemes will be considered from two standpoints, efficiency and economy.

With reference to the season between April and October, the months of April, May, June, September, and October may usually be considered as normal, while July and August will generally cover the periods of excessive motor-car traffic. The adoption of the first plan suggested would necessitate a minimum of one period of six or seven days in the normal months and one period in one of the abnormal months, preferably in August. It should be noted that both the normal and the abnormal Saturday and Sunday traffic are ascertained by only one set of observations in each case, a self-evident and unsatisfactory result of this plan if only two periods are to be taken. If more than two periods are advocated the expense entailed would be considered prohibitive. The second plan is open to all the objections raised against the first, and would prove more expensive provided enough days were used to secure an equal amount of information.

As a practical, economical, and efficient plan the following method is proposed for adoption under average conditions. For the season from April to October inclusive the traffic should be taken during four periods of three days each; one period being in April, May, or June, one in July, one in August, and one in September or October. As local conditions may dictate, either Friday, Saturday, and Sunday or Saturday, Sunday and Monday could be taken, thus ensuring information relative to the usual abnormal Sunday motor-car traffic and, in some cases, to traffic above the week-day average on Saturdays, while the Friday or Monday traffic would give a fair indication of the normal week-day traffic. It is evident that by this plan more reliable and essential facts are secured relative to traffic than by the other methods considered. From the standpoint of economy the advantage lies entirely with the proposed method, especially if the lowest paid members of the engineering department are employed on this work. Week-end trips involving the use of only one-and-a-half working days for the taking of the census during each period is a particularly satisfactory arrangement from the standpoint of the economical use of office time.

In the months from November to March inclusive two three-day periods would be taken in certain cases; one in November

or December, the other in February or March. This distribution of the periods would furnish statistics of the normal traffic in this season, and would also afford opportunity for a study of traffic detail and the condition of the highway during the winter season.

Instead of having the results of a year's observations upon which to base a design of a given highway, in many cases only a month will be available in which to make all the preliminary investigations. Three plans will be considered: first, a period of nine consecutive days beginning with a Saturday and ending with a Sunday; second, nine days of observations distributed as follows—Saturday, Sunday, and Monday of the first week, Tuesday of the second week, Wednesday of the third, Thursday of the fourth, and Friday, Saturday, and Sunday of the fifth week; third, a plan of three-day periods using three sets, one of Friday, Saturday, and Sunday, and two of Saturday, Sunday, and Monday, one period in the first week, one in the third, and one in the last week. It is obvious for the same reasons as in the former comparison that the advantage lies with the third method. From the standpoint of the Saturday and Sunday traffic, the third plan provides an average of three days, the first and second an average of two days without much opportunity for extra periods if the weather should prove inclement on abnormal traffic days. Although the first and second give more complete information relative to normal week-day traffic, it is usually unnecessary to take traffic on more than six week-days in order to secure satisfactory data relative to normal traffic in a given month. The months which will usually be used for short period observations are from March to August inclusive.

The number of consecutive hours which should be taken during the day will depend upon local conditions and the period of the year when observations are made. In many cases twenty-four hours will be absolutely necessary, while in certain cases twelve or fifteen hours will be satisfactory. The engineer who makes the preliminary investigations will ascertain the number of hours requisite. It must be borne in mind that the facts ascertained are used as a basis for an estimate of traffic and hence minute detail should not be obtained at unwarranted expense.

A. Moulleé states that in France the census is taken in the following manner: "The roads are divided into a certain number of sections, in each of which it is assumed that the traffic is more or less constant from one end to the other. At one point of the section, chosen as the point of observation, an observer notes on a printed form the vehicles and animals of each category which pass in front of him. The choice of the points of observation is of the utmost importance. For purposes of comparison of the censuses it is essential to have the points of observation the same in each case unless changed conditions make it absolutely necessary to shift. For a maximum of exactitude it would be necessary to divide a road into as many sections as there are branch roads, but this is, of course, impracticable. It is very important to have conscientious observers. Roadmen are usually employed for the purpose in France.

"The census is taken over the entire year, but it is too expensive to take it each day in the year. The method considered as the most practicable, from the standpoint of the elimination of undue effect of abnormal traffic upon the average result, is to take count upon single days at regular intervals. The last two censuses have been taken upon single days at a constant interval of thirteen days. Counting at night is done occasionally upon each section at such times as the engineer sees fit. It is usually desired to take at least one night count in each of the four seasons of the year."

What has previously been said in regard to taking traffic outside of cities applies to a method that may be adopted for this purpose within the cities. The method to be adopted in any case, however, will vary, depending upon local conditions. An investigation of the business interests situated on the street, the merchandise which is handled, and the general routes taken by traffic from the railroad centers or docks must be made before it is possible to decide on an intelligent plan for taking the census. In residential districts the problem is more simple and the method used would probably be very similar to that proposed for highways outside of built-up districts.

In connection with determining the congestion of traffic on

city streets, besides obtaining figures relative to amount of traffic passing a certain point in a given unit of time, the number of all classes of vehicles and street cars within a certain length of street in a given unit of time should be counted. Knowing the average speed of the different classes of vehicles and cars it can be ascertained whether or not traffic of one kind is being delayed by that of another kind. A study of the census will enable one to determine the advisability of widening the street.

Traffic Regulations. The existing traffic regulations and their enforcement should be carefully looked into, as, for example, the allowable loads and the prescribed width of tires; whether or not vehicles or tractors with extremely wide tires are required to keep to one side of the center of the road; the speed of motor vehicles, etc. As an example of the importance of this point might be cited the following. In one of the large cities of this country one of the main thoroughfares leading from the center of the city to the outskirts was built for a greater portion of its length as ordinary macadam. The allowable speed limit within the city limits was fifteen miles an hour. This regulation was strictly enforced for the entire length of the road with the exception of the last one-quarter of a mile from the city line. The increased speed at which the cars were driven over this last portion of the street caused the roadway to wear out much quicker than where the regulation was enforced. Similar examples are frequent in any large city, and if such facts are ascertained it is an easy matter to modify the construction at a slightly increased cost so as to prevent excessive maintenance costs at a later date.

Diversion of Traffic. The construction of roads and streets often necessitates the diversion of traffic during the period while work is being done. In the business districts, it is possible to close off one or two blocks or to build half the width at a time without inconveniencing the public to any great extent. On roads it is not such an easy matter to provide means for traffic to pass around the work, and if it cannot be accomplished it may preclude the use of some method that would otherwise be used.

CHAPTER III

SURVEYING AND MAPPING

Surveys For Roads

General Scope of the Work. The nature of the work does not demand the same degree of accuracy as is required in city surveying. The surveys are not usually tied in with any system of points previously established by triangulation or by closed traverses, accurately balanced. A survey on one road may be made entirely independent of that on another road, since the roads are usually so widely separated that there is no important relation between the two. Of course, adjoining surveys on the same road should be connected with each other, but it is not essential that the stationing should be continuous. A map showing the plan of the road system might be prepared in the course of time by combining the connected surveys. The accuracy of such a map, however, would be seriously questioned, on account of the errors involved in the methods employed in making the road surveys unless the latter are tied in with a system of points, well distributed over the area covered by the system, which have been established by precise methods.

Road surveying is often very much simplified, due to the fact that the proposed improvement follows an existing highway. The alignment of the old travelled way may be greatly improved by a judicious choice of tangents to eliminate the general sinuosity of the old line, and by flattening out or widening sharp curves. Changes of this character can generally be affected within the limits of the old right of way. Even if short détours are made beyond the limits of the old right of way, frequently the best position of the line can be determined by one survey, due to the fact that the extreme points are many times intervisible and that

the change in alignment is not so far removed from the old right of way, but that the advantages of the improvement can be readily seen on the ground.

The surveys for highways on entirely new lines are carried out about the same as in railroad work. The United States Geological Survey, in conjunction with the various States of the country, has prepared topographical maps that give the contours and location of highways. In mountainous country a good map will be of the greatest assistance, and if the map location of the highway is given the study it warrants, it may preclude the necessity of making more than one survey. If a map cannot be obtained, a thorough reconnoissance of the locality should first be made as in railroad work, and then one or more survey lines, the number depending upon the unevenness of the country, must be run before the best route can be determined upon. In relocating a road on the easterly side of Florida Mountain in Western Massachusetts from North Adams to Charlemont, a distance of fourteen miles, over thirty miles of preliminary lines were run.

The long straight lines of the old Roman roads are quite noticeable. Some investigators who have made a study of this subject believe that in locating the roads the Romans took some landmark in the far distance as a sight and built the road towards it, while others are of the opinion that they obtained the alignment at night by means of fire signals. That fire signals are still useful for this purpose is illustrated by the fact that they were used in locating certain portions of the Coleman du Pont Road in Delaware. The southern part of the State is quite level, and no maps existed by means of which the location could be facilitated. In order to avoid running several preliminary lines, rockets, which remained suspended in the air for practically a minute, were sent up at night from points which it was desired to connect, and a line of sight was obtained from observations made on these rockets.

A great deal of the information that is wanted in the preliminary investigation may be obtained at the time the survey is made. The survey to be complete should include a transit line

from which the location of all topography is made, and the levels showing the contour of the earth's surface for a width either side of the transit line sufficient to include the proposed construction.

The Transit Line. The transit line may or may not coincide with the proposed center line of the new road.

Transit Line as Reference Line. In some instances the transit line may only serve as a reference line on which the rest of the location is based, and as a working line from which the proposed work can be staked out. From the standpoint of convenience this method has several advantages. The traffic conditions may be such that the work will be constantly interrupted unless the line is run along one side of the highway, rather than near the center. It is the practice in some cases to stake each 50- or 100-foot station on the line as the survey is being made, the line being far enough removed from the center so that the stakes will not be disturbed during construction. The line of stakes serves as a convenient reference for any further staking necessary during construction. In some cases where a car-track is located in the road, the transit line may be made to coincide with the line of one of the rails. If this is done, it is a very easy matter to relocate the line at a later time, without the use of a transit, for purposes of measuring up the work or resetting stakes and securing additional information.

Transit Line Used as Center Line. The surrounding topographical conditions will govern the advisability of trying to obtain a field location of line that will be the best one from every standpoint. In many cases too much time is spent in the field to accomplish this result. If the country is generally flat, and if proper cross-section levels are taken, it will be possible by studying the plans alone to determine upon a final center line which in places might be several feet either side of the transit line without involving any appreciable error in the stationing; on the other hand, if the country is extremely rough, a change of line from the transit line made in the office might necessitate another trip by the field party to obtain information relative to the change. A material departure of the final center line from the transit line, however, is liable to change the stationing.

Considered from the standpoints of accuracy and expeditiousness of office work, the best transit line is the one that nearest approaches the final center line of the road.

Stationing and Referencing. The transit line should start from an initial point which may be a point on some previous transit line or some assumed point carefully tied in with more or less permanent objects. The line is made up of tangents and curves. In some cases, however, no account is taken of curves in running the line, a curve being replaced by a series of tangents which will approximate it. The fact that curves are taken account of makes the field work somewhat more laborious in that the P. C. and the P. T. have to be figured for each curve in order to obtain the correct stationing. When the external angle between the tangents is less than 10 degrees, the stationing may be measured around the tangents without appreciable error, although a slight curve may be built at the intersection; when the external angle between the tangents is over 10 degrees, it will be necessary to figure a curve in order to get the correct stationing. The line is stationed every 50 or 100 feet, depending upon the character of the topography and the accuracy desired for the estimate of grading. There are a variety of methods of obtaining the stationing around the curves. In the case of short curves the actual length of arc may be figured and the curve laid out by eye, being guided with the external and the P. C. and P. T. In the case of long curves, however, it is somewhat more convenient to lay the curve out by deflection angles. Since with this method the length of the curve is measured on the chords, a proper length of chord should be chosen in each case so that the total difference of the measurement of the curve by the chords and the actual length of arc will not exceed the allowable limit of error in the field work.

It should be borne in mind that any points established on the line are liable to be removed or covered up during the construction, so it is important that the points at the intersections of the tangents should be carefully tied in to objects that are permanent and readily accessible. If this part of the work is well done and good sketches are made showing the tie distances, it

will avoid considerable loss of time at a later date, when it is desired to rerun the line.

There are several methods of running the transit line and of locating topography with reference to it. Only one method will be described which, if used, will give results within the limits of accuracy necessary, and will also be as expeditious as any.

Field Party and Equipment. The party will comprise one transitman and three assistants who will serve at various times as either rodmen or chainmen. The equipment will consist of the following instruments: One transit, one 100-foot steel tape,

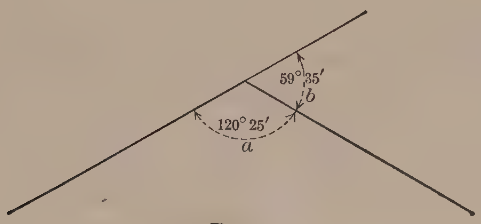


FIG. 9.

graduated to feet and hundredths, one 50-foot metallic tape, one self-reading level rod, equipped with a target, range pole, pins, plumb bobs, spikes, tacks, chalk, axe, etc.

Running the Line. The chief of party should first carefully plan out the location of the tangents and intersection points. If the transit line is to be used simply as a reference line, the same care will not have to be exercised as when it is desired to make the transit line correspond with the final center line of road.

The transit should be set up at the intersections of the tangents from which points the tangents can be run out in either direction. The angle between the tangents should be turned off at least twice and the mean value taken. The magnetic bearings of the tangents should also be taken as a check. The angle read may be the angle "a" included between the two tangents, or it may be the supplement of this angle, "b," known as the deflection angle, see Fig. 9. Due to the fact that the deflection angle will be used in mapping the survey, it will be more convenient to the office work if it is the one read and recorded in the

notes. By fixing temporary sights, which will not be disturbed during the progress of the survey, defining lines and points, much time will be saved that otherwise would be used by the men in giving sights from these points. The length of each tangent is then determined with the steel tape, the measurements being made to the nearest hundredth of a foot. Starting from the initial point the 50- and 100-foot stations are marked on the tangents by pins or by spikes driven through a piece of cloth. If the angle at the intersection is large enough to warrant the use of a curve, the stations of the P. C. and P. T. of the proper curve should be figured and marked on the line.

Taking Topography. The topography includes the shape of the ground and all of objects such as houses, walls, fences, gutters, curbs, culverts, bridges, catch-basins, trees, monuments, edges of travelled way, poles, ditches, etc., in fact, any object that occurs within the limits of the survey that would be of importance in designing the road. Methods of taking topography which define the shape of the ground will be considered under "levels."

All topography is located with reference to the tangents. One of the easiest and quickest ways to locate the greater part of the topography is by perpendicular offsets from the transit line. This method of location also makes the plotting very much more simplified. For example, in locating the topography, such as fences, walls, and curbs, it is sufficient to record the stations on the transit line opposite which they begin and end, and the stations at intermediate points which will define their alignment. The offsets are the perpendicular distances measured from these stations on the transit line to the points of the object previously noted. The perpendicular direction will be estimated by eye, and if the object is not at too great a distance away the results obtained are sufficiently accurate. The offsets and the plus distances from the 50- or 100-foot stations, previously established along the tangent, may be conveniently read by means of the metallic tape. Offsets and plus distances for location should never be measured closer than the nearest tenth, and in many instances where the topography is not at all

well defined, the nearest foot will be sufficient. Measurements should be taken to the face of walls, fences, etc. When the P. C. is reached, the location of the topography should be made from the tangents. The distance along the tangent can be recorded as a plus distance from the P. C. to the intersection. Starting again at the intersection a plus distance from the latter can be employed the P. T. Beyond the regular line stationing may again be used. If the curve is laid out by means of deflection angles, the topography may be located from the subchords which subtend the arc, in which case, of course, the regular line stationing should be used between the P. C. and the P. T. Highway lines and property lines, which intersect the transit line at an angle, may be located by noting the station on the transit line at which the line in question, if prolonged, would intersect it, together with the perpendicular offset to the corner from the station opposite this point. The two stations and the offset will completely locate the line.

The location of all objects included under topography may be accomplished in a similar manner. In places of importance, such as squares and villages, where the location by these methods might be somewhat difficult, the topography can be readily obtained by taking angles and distances to the various points or by means of the stadia. The last method will often be found very convenient in locating objects some distance away from the transit line.

If it is necessary to survey parcels of land along the sides of the highway, it may be accomplished by enclosing the parcel with a transit line which is referenced inwith the transit line of the survey.

Recording the Notes. The notes should be recorded by the chief of party and should progress from the bottom of the page to the top. For the sake of clearness it is better to sketch the line as it actually occurs rather than to represent it by a straight line up the center of the page. A sample page of transit notes is shown in Fig. 10, in which many of the points above mentioned are illustrated.

Levels. The information required to locate all topography

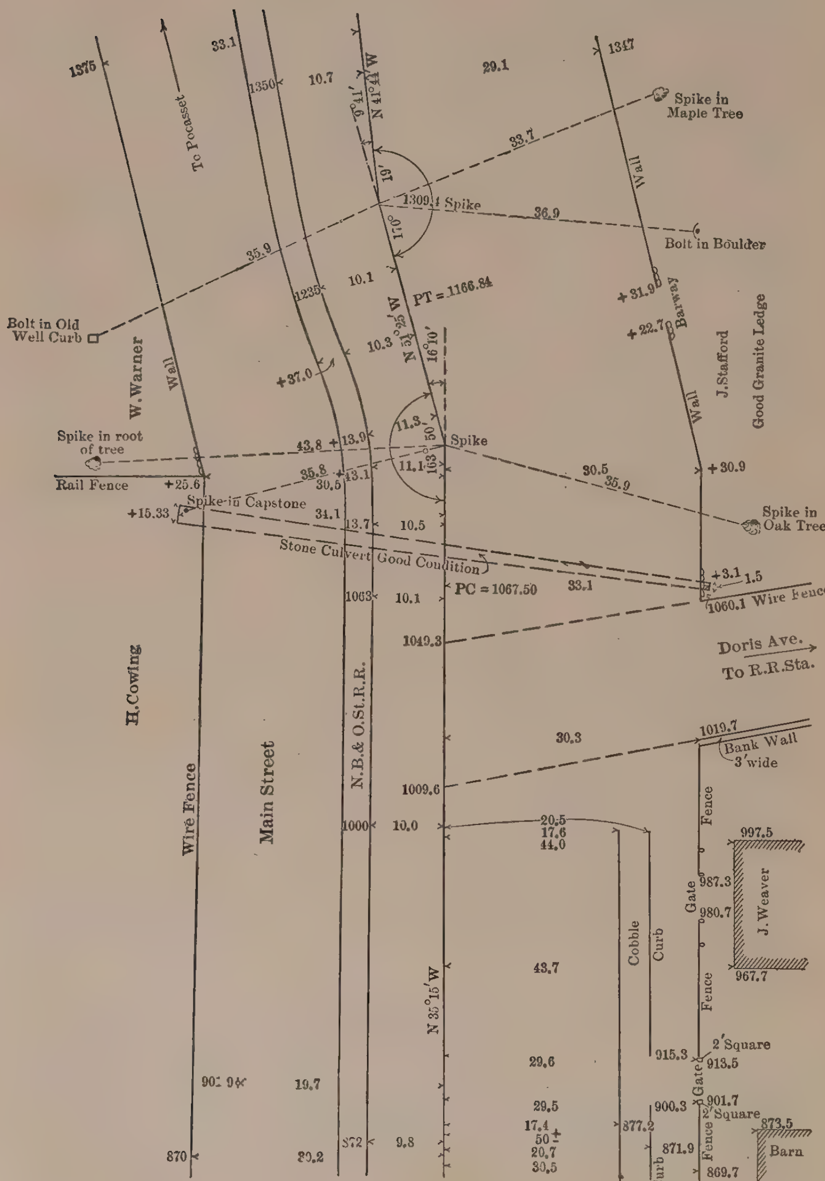


FIG. 10. Sample Page of Transit Notes.

is completed by taking what is commonly called "cross-section levels." From the information thus obtained both the profile of the transit line and the shape of the earth's surface at known intervals along the transit line can be plotted.

The necessary levels may be taken by the same party that runs the transit line or by a separate party. If the work is done by the same party that is running the line, the line and location of topography can be completed before starting the levels, or the levels can be taken on the different portions of the line as they are run out, and thus the whole of the work be completed as it progresses.

Bench-Marks. In many States lines of levels have been run starting from a government bench, and bench-marks have been established on these lines at various points so that it is not a difficult matter to get a tide water datum for the levels on any road. If this has not been done, the datum must be assumed. If a good contour map is available, a datum may be assumed which will approximate the actual height of the ground above tide water. Otherwise, any datum can be assumed so long as it is of sufficient height that no minus elevations will occur in the survey. Points for bench-marks should be of a stable and permanent character, and their location should be clearly described so that they may readily be found at any time. At least one permanent bench-mark should be established every 1,000 feet along the survey.

Running the Levels. The levels may be taken either with a transit or with a level. The transit, if in adjustment and carefully used, is sufficiently accurate for the work, but, of course, it would not be used in establishing a long line of bench-levels. When the rod is held on a B. M. or a T. P., the target should be set as a check and the rod read to the nearest hundredth. In obtaining the elevations of the earth's surface, it is not necessary to use the target or to read the rod closer than the nearest tenth. The measurements of the plus stations and offsets to points at which levels are taken may be made by means of the metallic tape. The chief of party takes notes, one man runs the instrument, another holds the rod and the

zero end of the tape, the third man holds the other end of the tape and calls off the distances to the points at which the rod is held.

Enough points should be taken to show correctly the configuration of the earth's surface. This may be accomplished by taking elevations at each 50- or 100-foot station along the transit line, one elevation being taken on the transit line and sufficient elevations being taken on a line perpendicular to the transit line at these stations to define the changes in slope of the earth's surface. The elevations of car-tracks, curbs, gutters, edge of travelled way, bottoms and tops of banks, together with their distance out from the transit line, should be taken in all cases. Care should be taken to extend the levels out far enough either side of the transit line sufficient to cover the proposed construction, and where heavy cuts or fills are liable to be made, this will require some forethought on the part of the chief of party. In addition to taking levels as described at every 50- or 100-foot station along the transit line, elevations should also be obtained in the same manner at those stations on the transit line which mark a change in slope. Center line profiles should also be run along every intersecting street and driveway for a distance of at least 200 to 300 feet from the transit line. Elevations should be taken at the corners of houses, at the ground line and at the sill where there is any possibility of the improvement disturbing the property. The elevations of the tops and bottoms of all culverts and drains at both ends should be determined. A line of levels should also be run along the ditches to culverts at both the inlet and outlet ends. In the case of bridges, elevations should be taken of bridge seats, bridge floors, tops of parapet walls, high water marks, points that will define the stream bed at the bridge and points along the banks of the stream above and below the bridge.

Some engineers prefer, in obtaining cross-section levels, to run a line of profile levels with the instrument on the transit line, and to work up the cross-section levels by means of a hand level. In this case it is not necessary to figure any elevations other than those on the transit line, since the points defining the cross-sec-

tions are known from the rod readings which give their distance above or below the known center height.

Check levels should be run between the turning points and bench-marks at the end of each day's levelling, or, if the work is done from time to time, the check levels should be run at the completion of each portion of the work.

Recording the Notes. There are several ways of recording the cross-section level notes. In one method, a sample of which is shown in Fig. 11, it will be seen that the levels are carried down in a column starting from the top of the page in a similar manner to recording any form of level notes. Under the column headed remarks, the distance of the point from the transit line and the description of the point are given. This form of notes takes up more space than the other form which is shown in Fig. 11*a*, but it is exceedingly clear, and if one book is devoted to each survey, there should be plenty of room for the notes. It will be noticed in the last case that the notes are recorded in the form of fractions, the rod reading being the denominator and the distance out from the reference line being the numerator. The distances out may be measured from the transit line or from stakes, the location of which is known.

Final Surveys. It is thought essential by some engineers to make a survey of the work after completion before making the final payment. The methods of making such a survey would be the same as those just described. The information desired is similar in character to that obtained on the first survey except that it refers to the finished work.

Staking Grades. Two methods of staking grades are in common use. One method is to drive stakes at the time the survey is made. The ground elevations at the stakes and elevations on tops of the stakes are taken. The stakes are driven on either side of the transit line far enough away so that they will not be disturbed during construction. Along tangents the stakes are placed at intervals of either 50 or 100 feet. On curves they may be spaced as close as 25 feet, depending upon the length and nature of the curve. When the grade of the road has been es-

tablished, the grade elevations at the stations where the stakes are driven can be determined in the office. The difference in height between the established grade and the tops of the stakes is recorded on a sheet, which is sent to the inspector on the work, who is thus able to define the grade.

In the other method stakes are not driven until after the

B.S.	H.I.	F.S.	Elev.	Bolt in boulder East
			50.00	B.M. side Sta. 531 ±
3.19	53.19			
		5.5	47.69	600 C
		5.9	47.29	7.5 left
		6.1	47.09	12.0 " T.W
		5.8	47.39	11.5 R.T.W.
		6.3	46.89	17.0 Rail
		6.5	46.69	65.0 C
		7.1	46.09	8.0 left
		7.3	45.89	12.5 " T.W.
		6.7	46.49	10.0 R.T.W.
		7.2	45.99	16.0 Rail
		9.3	43.89	25.5 ledge
		12.34	40.85	C. B. house left T.P. side Sta. 619
5.57	46.42			
		4.8	41.62	700 C
		5.2	41.22	9.5 left
		5.9	40.52	12.0 " T.W.

FIG. 11. Level Notes.

grade has been determined in the office. The stakes are then driven as before and notches are cut on the stakes, generally placed so as to be some even foot above or below grade. The stakes should be at least two feet long, and approximately two inches square. In this method all information is marked on

the stakes. The sides of the stake facing the center of the road are marked with the distance of the notch above or below grade. On the opposite faces of the stakes on one side of the road is marked the station. The opposite faces of the stakes on the other side of the road are marked with the distance from the face of the stake to the finished center line. It may be neces-

Sta.	+	H.I.	—	Elev.	
B.M. No. 1	Spi	ke in root of	elm tree eas	t sta. 0 + 20	
	5.62			100.0 (As	sumed)
		105.62			
0	28	17 9	0 11	19	36
	9.5	11.5 10.5	9.3 10.1	11.5	12.4
Bridge	Top floor		10.5	95.12	
Bed of	stream		14.6	91.02	
1	30 27	13 5	0 13	20	27
	10.3 7.9	7.3 5.9	5.6 6.3	7.1	6.9
2	25	16 7	0 9	15	21 30
	6.3	5.6 3.6	3.1 3.9	4.3	4.7 4.6
T.P.	4.85		4.33	101.29	
		106.14			
3	23	19 10	0 10	20	35
	12.4	11.9 11.3	10.1 10.7	10.8	12.1

FIG. 11*a*. Level Notes.

sary when a stake comes in a driveway or at some other point where traffic must pass over it, to drive the stake flush with the ground. These stakes are recorded as flush stakes and the grade is referenced to the elevations of their tops. A sheet showing the relation between the flush stakes and the grade should be given the inspector.

Recording the Notes. In Fig. 12 is shown a sample page of notes made as a record of marking grade stakes according to the last method. The elevations given in the fifth column are those of the grade at the center of the road obtained by computing the

center line grade. Knowing the height of instrument, the rod reading which would give a grade elevation is determined by subtracting the elevations in the fifth column from the height of instrument, the results being entered in the F.S. column opposite their respective stations. The rod is then held at the grade stake and moved up or down on the stake until a rod reading is obtained which is the same as that called for under the column F.S., or which differs from it by an even number of feet. A notch is cut in the stake at the point giving the reading, and the reading

Sta.	B.S.	H.I.	F.S.	Elev.	R.	L.
B.M.	Bolt in boulder east side sta. 531 ±			50.0		
	4.53	54.53				
500			7.28	47.25	6.28 1′ ↓	7.28 Gr.
550			7.68	46.85	9.68 2′ ↑	8.68 1′ ↑
600			8.08	46.45	8.08 Gr.	9.08 1′ ↑
650			8.60	45.93	9.60 1′ ↑	7.60 1′ ↓
T.P.			12.21	42.32		
	3.17	45.49				
700			1.92	43.57	3.92 2′ ↑	4.92 3′ ↑
750			3 24	41.25	3.24 Gr.	3.24 Gr.
800			5.62	30.87	6.62 1′ ↑	5.62 Gr.

FIG. 12. Grade Notes.

obtained is entered in either of the last two columns, R. being for stakes on the right of the road and L. for those on the left. A rod reading less than the rod reading under the column F.S. means that the elevation of the notch is higher than the elevation of the grade at the center and the stake should be marked so many feet down; a rod reading which is greater would mean that the stake must be marked so many feet up, as the elevation of the notch is below grade. The marks which are put on the stakes are entered in columns R. and L. as 1′ ↓, 2′ ↑, etc. When a rod reading can be obtained on the stake the same as that under the column F.S., the notch is marked Gr. or grade.

Setting Slope Stakes. Slope stakes, defining the ends of the slopes, should be set where the cuts or fills are heavy. The position of slope stakes can be most easily determined by measuring the distances on the plotted cross-sections from the finished line to the edge of the slope. These same distances can then be laid off in the field at their respective stations. If, on the other hand, the work was through an extremely rough country, and no cross-sections had been plotted, the slope stakes would be set by instruments in the field as in railroad work.

Mapping Road Surveys

The Plan. The survey plan may be plotted on a continuous roll of detail paper in one-mile lengths; the scales usually used are either 40 or 50 feet to the inch. The transit line is first laid out on the sheet. This may be plotted by either of two general methods. One is to compute the coördinates of the several intersecting points of the tangents with reference to one

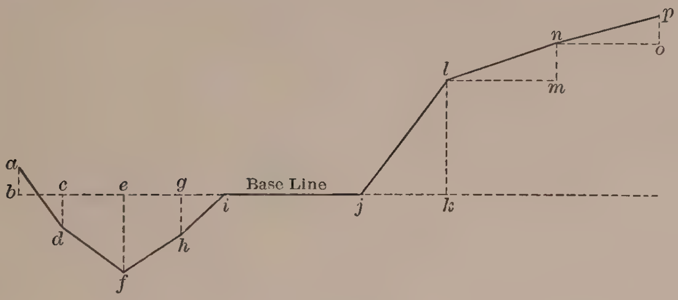


Fig. 13. Coördinate Method of Plotting Transit Line.

of the tangents as a base line. The tangent selected as the base line is drawn parallel with one edge of the paper and in such a position on the sheet that the transit line, when completely drawn, will not run outside of the limits of the sheet (See Fig. 13). Sometimes the transit line is so tortuous that it is impossible to plot it on the sheet without making one or more breaks in the line. The plotting should be carefully done, and as a check the angles between the tangents should be read with a protractor

and the length of the tangent should be measured between the points as obtained by the coördinates. In some cases the paper may be first ruled off into large squares of a definite size in order to facilitate the plotting of the coördinates. It is not necessary to do this, however, since all the coördinates may be plotted by perpendiculars from one base or by plotting the coördinates for each individual tangent with the last point of intersection as the origin.

Another method which is quite similar, fully as accurate, and more rapid since it eliminates the necessity of drawing a rectangular system of coördinates, is the so-called tangent

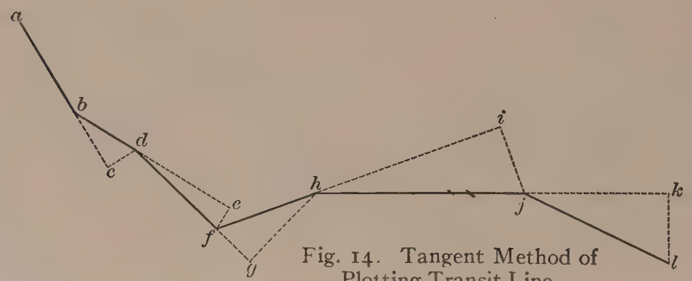


Fig. 14. Tangent Method of Plotting Transit Line.

method in which the lines are run out and the tangential offset plotted (See Fig. 14). In this case the prolongation of each tangent serves as a base from which the tangential offset is plotted to obtain the next intersection. The best position of the transit line on the paper will have to be found as before.

A very common method is to plot the line by means of a protractor and scale. It is impossible to plot the line as accurately by this method, however, no matter how finely graduated the protractor may be.

When the line has been correctly laid out, the curves, if there are any, should be drawn in and the stations should then be marked off on the line and the survey plotted from the notes. Any of the conventional topographical signs can be adopted for the detailed topography. It is essential to have the names of all property owners written in on the plan.

The Profile. The profile may be plotted on this same sheet

and it is generally placed below the plan at the bottom of the sheet. The datum line is drawn and an elevation assumed for it which will be sufficiently low so that when the ground line is plotted, it will not fall below the datum line at any point. Stations are marked off on this base line corresponding to the same stations on the plan, and perpendiculars are erected from the datum line. Since the plan is a series of straight lines and curves, a perpendicular dropped from a station on the plan will not necessarily coincide with the same station on the profile. This is a matter of convenience only, however, and in studying the plan it will be found that there is some portion of the line where the stations in plan and profile can be made to come perpendicularly over each other. The plan and profile are so arranged and the remaining portion of the profile is allowed to come as it will. The ground line of the profile should represent the profile of the original surface on the proposed center line of road. If the transit line corresponds with the proposed center line, the elevations taken on the transit line will be the ones used, otherwise the center line elevations will have to be obtained from the cross-sections. The ground line elevations are written and plotted on the verticals corresponding to their respective stations. The points thus obtained are connected with straight lines. Culverts, bridge openings, elevations of car rails adjacent to the improved surface, manholes, curbs, corner boards of houses, etc., should also be plotted on the profile so that when the grade is determined, all the necessary information will be at hand. The same horizontal scale used for the plan is used in scaling off the stations of the profile, but the scale used in plotting the elevations is much greater. If the horizontal scale of the plan is 40 feet to the inch, the vertical scale of the profile is generally taken as 8 feet to the inch; if the horizontal scale is 50 feet to the inch, the vertical scale is usually made 10 feet to the inch. Sometimes the profile is plotted on translucent profile paper such as is used in railroad work. Some time will be saved if this is done since it will not be necessary to draw a base line and erect verticals from it. It is advisable to ink in the ground line of the profile since in determining the

grade line many erasures may be necessary before the final grade is adopted.

The Cross-Sections. The cross-sections should be plotted either on cross-section or profile paper. The scale used should be as much as ¼ inch to the foot, since the estimate of cut and fill is made from these cross-sections, and the use of a large scale makes the determination of areas more accurate. The cross-sections are sometimes plotted and inked in on translucent paper in which case it is possible to obtain blue-prints. They are also plotted on ordinary profile paper which, due to its finer subdivisions, makes the work of plotting the points somewhat easier. In some offices cross-sections are plotted on a sheet of plain tracing-paper placed over a sheet of cross-section or profile paper, which serves as a guide and scale in plotting the various points. The plotted sections are then inked on the tracing-paper as a matter of record.

It is the custom of some offices to furnish the men in the field with plans and cross-sections of the proposed road. In some of the larger states, where the engineering force is quite large and the drawings are made at a central office, it is essential for each engineer in charge to have a copy of the plans. This is most readily accomplished by making blue-prints of the original drawings. The blue-prints should be made on sheets of a standard and convenient size. In tracing the drawing of the plan and profile, the sheets of tracing-paper can be cut to the desired size and as much of the drawing traced on this sheet as it will contain. The roll of paper on which the cross-sections have been plotted can be cut into sheets of a corresponding size for blue-printing. When the blue-prints have been made, the whole set can be bound together. A convenient size of sheet is one measuring about 2 feet wide and 3 feet long. Each sheet should bear a title describing its content.

A reproduction of a plan as made by the Massachusetts State Highway Department is shown in Plate I. Plate II is a reproduction of the highway plans made by the Board of Water Supply of New York City. It will be noted that the contours have been recorded on this plan in a similar manner as is done

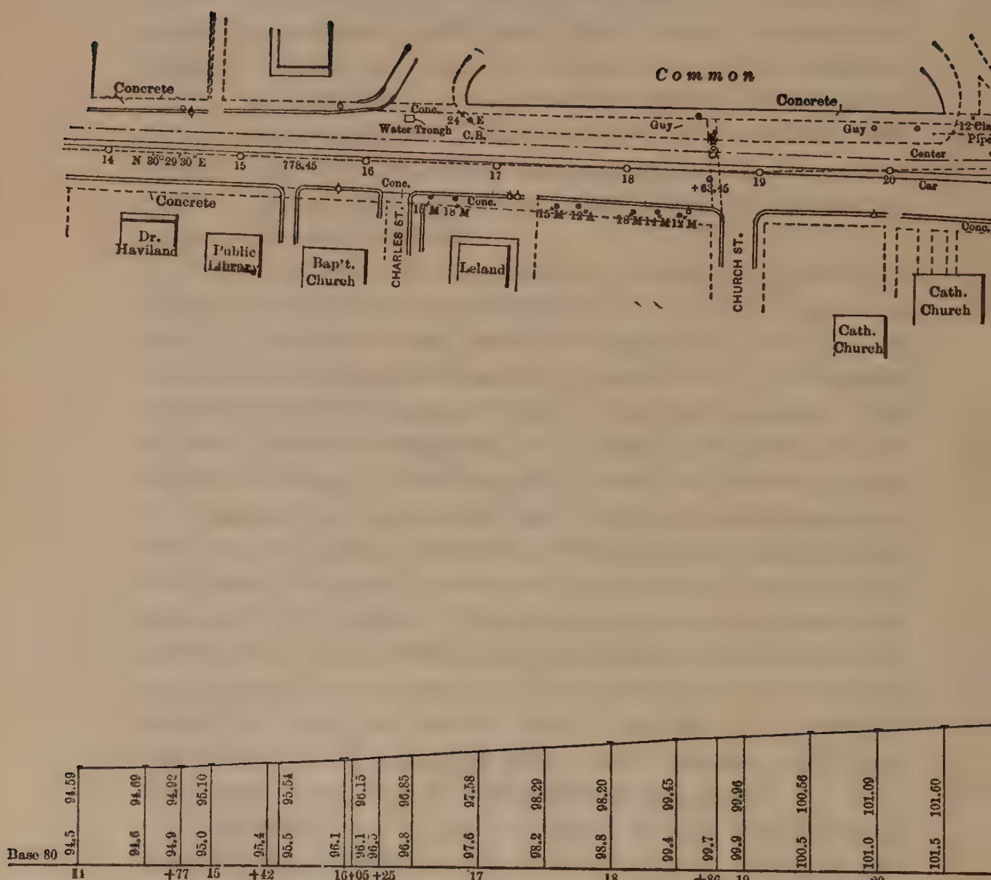
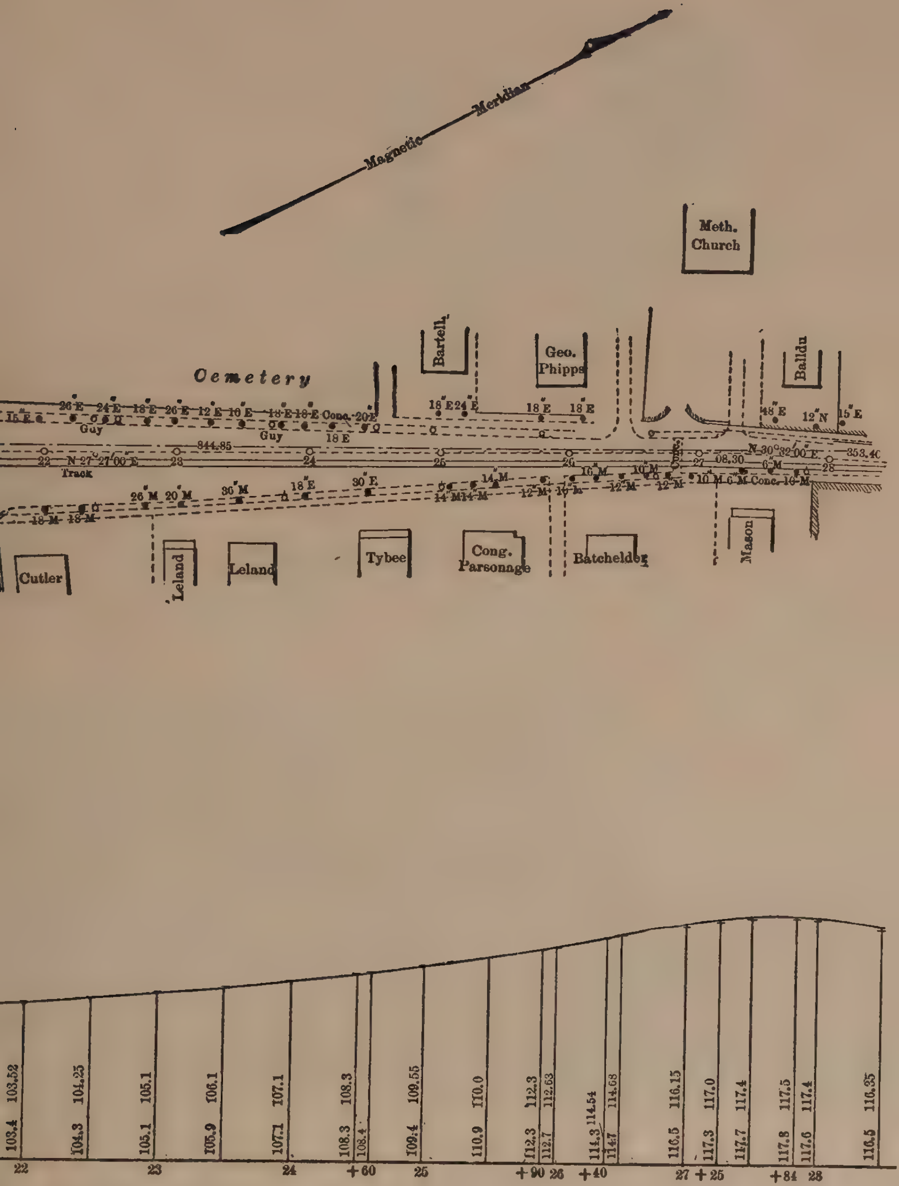
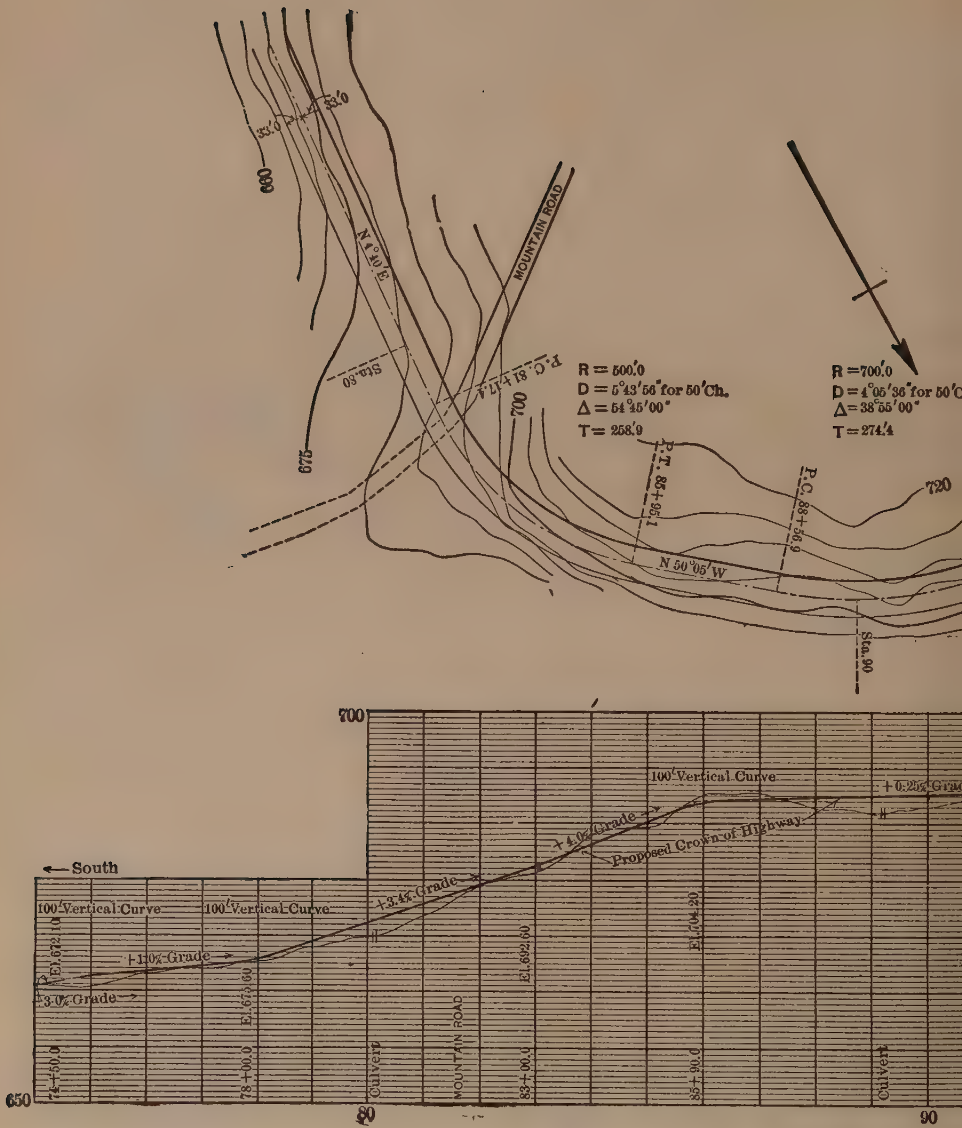


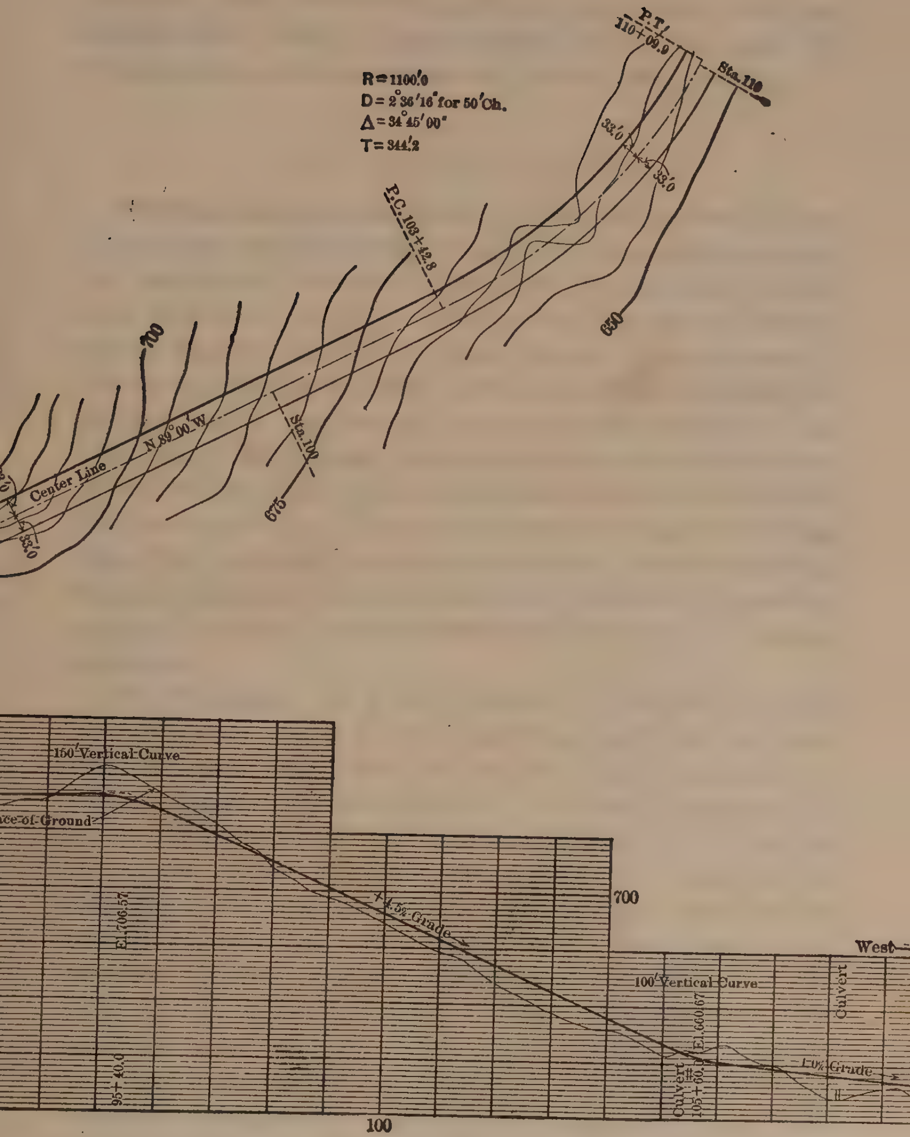
PLATE I. Plan and Profile of Road, Prepared



...usetts State Highway Commission.



PROFILE ON CE



City of New York
BOARD OF WATER SUPPLY
ASHOKAN RESERVOIR
SUBSTITUTED NEW HIGHWAY
ROAD NO. 1
SCALE

in railroad work. Where the grading is particularly heavy and through new country, some engineers prefer to record the topography this way rather than by plotting cross-sections.

Surveys for City Streets

General Scope of the Work. As streets are closely related to each other and the property bounded by the streets is valuable any inaccuracies in surveys may mean extensive and troublesome litigation. In order to study the situation intelligently and to draw up a plan for a street system, it is necessary to make a topographical survey of the area, which will include all existing streets, monuments, property lines, waterways, contours, etc. The extreme accuracy required makes it necessary to use somewhat different methods than those which would be adaptable for roads. The endless trouble ensuing from existing old surveys has been the cause of resurveying many of our larger cities according to up-to-date methods. Additions of suburban areas to the cities have also necessitated surveys of a similar character.

The Traverse. It is first necessary to project lines over the area from which the existing topography can be taken. One method of doing this is by means of closed traverses. A closed traverse is run and balanced. Secondary traverses which would be balanced are run with any of the sides of the first traverse as a base. A third system of traverses might be run from the second and so on until sufficient lines were obtained to fully cover the area. This method involves some inaccuracies, however, since in balancing the traverses a local error is distributed throughout the entire traverse. In making a topographical survey of Staten Island, New York, it was necessary to carry on the survey before points of control could be determined by triangulation. The traverses were limited to 10,000 feet in perimeter and were made as nearly square as possible. Each section was made up of ten or more traverses which were adjusted one to another commencing with the one having the largest error of closure. The traverse work was built up ex-

tending outward over the first adjusted section and well in advance of the detailed topography. Measurements were made with standard 100-foot steel tapes, using a 16-pound pull. The ends of the tapes were supported on tripods without intermediate supports, and the temperature of the tapes was taken during the measurements. Each line was measured twice and the two measurements had to agree within 0.01 x (0.00003 x distance in feet).

Traverse with Triangulation Control. The following method is a more accurate one. The United States Coast and Geodetic Survey have made triangulation surveys of many of the states of this country. Enough points on the system may generally be found within the city limits to furnish a triangulation system on which the rest of the work can be based. If enough points cannot be obtained, a triangulation survey should be made of such scope as to provide lines in the system well distributed over the area and so that points whose precise positions are known would be situated say between 2,000 and 5,000 feet apart. The triangulation work should be done with the utmost refinement and the points established should be permanently monumented. Points on the triangulation system can then be connected by traverse lines, and the accuracy of each traverse definitely determined by calculation. The system of triangulation thus serves as a control since points are connected, the location of which has been accurately determined. Points established by the traverses or by secondary triangulation are monumented as desired. The detailed topography is filled in from these traverse lines which should be chosen so as to facilitate this part of the work. The result is that the area is covered with a network of lines, the position of which is referenced in with one main system. The coördinates and any of the points in the system can be figured, which makes it a simple matter to replace them at any time if they should be disturbed or lost. Since the accuracy of each individual traverse line can be checked, any bad errors are eliminated that in balancing a closed traverse might not be apparent. The origin from which all coördinates are figured should be taken entirely to one side

of the area surveyed so that all coördinates will be to the right and above the principal coördinate axes. The convergence of the meridians does not need to be taken into account in figuring the coördinates, and the curvature of the earth's surface can also be neglected.

In making a topographical survey of the city of Baltimore this method was used. Approximately 5,000 traverse lines were established within the triangulation system and the maximum error of closure permitted was 1 in 15,000. A similar method was used in surveying the Borough of The Bronx, N. Y.

Levels. Bench-marks should be established by running closed circuits of precise levels. The level datum generally taken is mean low tide. In the survey of Staten Island, the circuits were all about the same size as the primary traverses. The bench-marks were established in pairs and the levels for each circuit, run with a Y-level, were adjusted in a manner similar to the adjustment of the traverses. In the survey of the city of Baltimore 600 precise level bench-marks were established from which 2,000 Y-level bench-marks were run.

Instruments Used and Standards of Accuracy. It is necessary to use transits in running the traverses in this class of work which are graduated much finer than those used in road surveying. A transit with a limb divided to read at least 30 seconds and preferably 20 or 10 seconds will give the best results. The tapes used should be standardized by comparison with the standards at Washington or with any other fixed and well established standard. E. H. Holden, M. Am. Soc. C. E., in describing the traverse work in connection with the triangulation of the Borough of The Bronx, New York,* said:

"In general, traverses connecting the triangulation stations are called primary traverses. They are made with utmost care, every precaution being taken to exclude errors, the chaining being done in duplicate, and the two results should not differ more than 0.02 per 1,000 feet and work should be done on cloudy days whenever possible.

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* See Engineering-Contracting, June 2, 1909.

"In primary traverse work, the tape is not used level, but on slopes which are measured, and constant tension is maintained by the use of mechanical stretchers, the temperature is determined by thermometers attached to the tape itself, and the tape held by stakes or portable tripods.

"The tapes are standardized exactly in the way they are used in the field, *i.e.*, supported in the same way and with the same tension. Thus no correction is necessary for sag or tension. For secondary traverses, the regular city engineer's 50-foot spring balance tapes are used with plumb bobs and tacks in the ground for marking pins.

"Equal care is taken with the measurements of angles, at least two sets of six repetitions each being taken, and closing the horizon so that the closing reading shall be within at least 10 seconds of 360 degrees. These limits have been easily maintained under normal conditions and reduce the traverse error to ¼ of an inch per mile, which is the minimum distance between the triangulation stations."

Monumenting the Lines. The topographical survey when completed is mapped. With the aid of these maps a design of the street system can be worked up that will best fit the natural conditions. The positions of all the street lines can be determined and the points chosen which are to be monumented. The location of the monuments can be computed and their position established in the field. Monuments of a permanent character sometimes are set in advance of any improvement and it will be necessary in the course of construction work to reset them if they are going to be disturbed. They are set at the intersections of center lines of streets; or at one side of the center; or only on one side of the street or on both sides. Monuments set within the carriageway are almost sure to be disturbed. A better location for them is in the sidewalk at a certain distance out from the property line so that they will always be intervisible and readily accessible. An area that is defined by frequent monuments all of which check up with the recorded measurements on a plan is rarely found. In new work laid out by modern methods of surveying, there is no reason why the monuments should not

be accurately located. Unfortunately, however, there is very little new work which is not complicated by the presence of lines already monumented, which have to be adhered to although in error. The problem becomes exceedingly intricate at times and a great deal of care, patience, and judgment must be exercised in order to arrive at its best and proper solution.

Survey for Grading. When a street has once been correctly monumented a detailed survey of the street can be obtained previous to the proposed improvement. The transit line can be referenced in with the existing monuments. Houses and other topography should be located by some accurate method such as angles and distances. The cross-section levels can be taken by the same general methods as outlined in road surveying, except more accurate work is required. The center line grade would be staked in the same manner as previously described. If no curbs are set before the pavement is constructed the same grade stakes may again be used to furnish the grade of the finished pavement, but first their elevations should always be checked up.

Survey for Repaving. In making a survey for repaving an old street that is curbed, a profile should be made showing the elevations of the curbs on either side of the street, if a change of grade is desirable. The new grade of the curbs is computed, the curbs are staked out and reset to the new grades and the remainder of the work progresses as before. If the grade of the curbs is not to be changed, the desired information can be obtained by measurements made from the tops of the existing curbs.

Staking Curbs and Grades. There are two methods that are commonly used in staking out curbs. In one the stakes are driven to one side on an offset defining the line of the curb and the tops of the stakes are made to conform to the grade of the curb. In the other method the stakes are driven on a line as before with their tops flush with the ground and a sheet of instructions is furnished which gives the distance above or below the top of the stake to the grade of the curb. Theodor S. DeLay, City Engineer of Creston, Iowa, during the summer

of 1911, made inquiries of engineers throughout Iowa as to their preference of the above methods. Twenty-five out of forty-one engineers expressed themselves as being in favor of the latter method. Mr. DeLay's opinion* in the matter, speaking of the last method, in brief is as follows :

"It is the easiest and quickest method. One set of stakes serves for both preliminary grading and finished work. Any second levelling done on the stakes serves as a check on the first levelling. The stakes are solid and out of the way of injury or disturbance and are more likely to remain in place until final inspection than stakes which are set to grade. The use of the grade sheet or written instruction renders it easy to direct the constructor with any further instructions relative to a deviation from the usual form of construction. The stakes may be driven at the time of making the preliminary survey and the levels taken on them are sufficiently close for making profile and establishing grade."

Curbs and gutters are usually constructed in advance of the street pavement. The crown and grade of the pavement may be regulated by setting lines of stakes transversely to the street at intervals sufficiently close to define the desired shape of the surface. In the case of very wide streets, street intersections, and public squares, it is advisable to use this method. On the narrower streets, however, the engineer may be furnished with a grade sheet showing the cuts and fills at the various points along and across the roadway, the same being measured from the tops of the curbs which have already been set to grade. By means of template boards, T-rods or lines, stakes can be set as desired during the construction without having to depend upon instrument work. Points can be set for different parts of the work as subgrade, foundation, and surfacing. If a stake is misplaced, the information is at hand by which it can be reset. It is always an easy matter to check up the work as the curbs furnish a permanent reference which is always convenient. It is the easiest method because it eliminates a great deal of

* See Engineering-Contracting, March 27, 1912.

field work which would otherwise be necessary and when once done is completed.

Catch-basins, manholes, and other appurtenances should be staked out so that their proper elevations may be maintained. It should always be remembered that stakes are liable to be disturbed and they should be placed so as to reduce this possibility to a minimum.

Mapping Street Surveys

Topographical Map. The topographical survey of the city should be plotted by the system of rectangular coördinates. On this plan should be shown all of the triangulation points, traverse points, as well as all the topography. Such a map would be made to scale of 200 feet to the inch. Contours should be shown at intervals of not greater than 5 feet. With this scale it is possible to represent a large area on a sheet of practicable size and have the topography in sufficient detail so that an intelligent study of the street plan as a whole can be made. Sectional plans can be made of any portion of this map to as large a scale as is desired when working out the details of any particular locality. If plane tables are used on the survey, the topography may be plotted in the field. In such a case a scale as large as 50 feet to the inch could be used. Later the sheets could be replotted at a smaller scale and combined into a number of general maps, which are then photographed. The negatives of the different maps can be carefully matched together and the whole can be reproduced on one sheet of a practicable size by means of photo-lithography. In this way as many maps of the whole plan can be reproduced as are necessary.

The plans, profiles, and cross-sections of the individual streets are plotted in a similar manner to that described for roads.

CHAPTER IV

DESIGN

Scope of the Design. A complete design comprises the consideration of the following factors: the highway system, traffic and its effect, width, grade, alignment, crown, drainage, foundation, type of surface, and estimate of cost.

Development of Highway Systems. There are several classes of highway systems which may be designated as follows: national, state, county, town, city, park, and estate. In the development of a system of highways of any class the importance of the design of the system as a whole is many times lost sight of. A glance at the road maps of many of the States, and the active interest and discussion in the betterment of conditions in some of our largest cities, involving mainly changes in the street plans, provide sufficient evidence that this is a fact. The consideration of systems will be taken up from the standpoint of the State, park, and city before considering the different elements of the design of roads and streets in detail. National, county, and town highway systems are governed by the same general principles as those of States, and estate highway systems are very similar to those of parks, hence a discussion of state, park, and city systems will cover all cases.

State Highways. Many of the States in this country lack a broad, comprehensive, and connected system of highways due to several reasons. Some States which construct roads under a state-aid plan are handicapped by the fact that any town, which has the money, can demand state aid for the construction of any piece of road within its borders regardless of its location. The result of this form of legislation is the construction of innumerable short sections of road throughout the State that are not connected and are of purely local benefit, sometimes restricted alone to the property owners residing adjacent to

them. In the course of many years a system of highways will be obtained, but if the control were in the hands of the State instead of the town, a system of highways could be acquired more quickly and the construction of the more purely local roads delayed. There are some States, on the other hand, that have adopted a connected system of roads which, when built, will make all parts of the State and its large centers readily accessible.

The design of a system of State trunk highways is simplified if a comprehensive topographical map of the State is at hand. The topographical maps made and furnished at a small cost by the United States Coast and Geodetic Survey serve the purpose in an excellent manner. If such maps or other topographical survey are not obtainable, a map showing simply the roads in plan can be used, but with the latter the study cannot be made in as satisfactory a manner except by doing a large amount of reconnaissance work in the field. The interstate trunk lines, the interurban trunk lines, and popular routes of travel should be selected first. Information should be obtained from the officials in the adjoining States relative to the main roads in those States so that the systems in the two States can be connected. The intrastate highways can next be added to the system. These highways pass through towns and connect towns situated within a few miles of each other. Before deciding to include any section of road in the system, a general idea should be obtained as to the practicability of its construction at a reasonable cost, and it should be ascertained whether or not the road is the best one to be built from the standpoint of the welfare and development of the communities through which it passes.

Park Highways. An ideal park system for any city or community would be one in which all of the spaces reserved for parks are connected with picturesque boulevards. In this country the great benefit which may be derived from parks does not seem to have been appreciated until a few years ago. Now, however, many of the States and cities are striving to take advantage of their present opportunities in this direction.

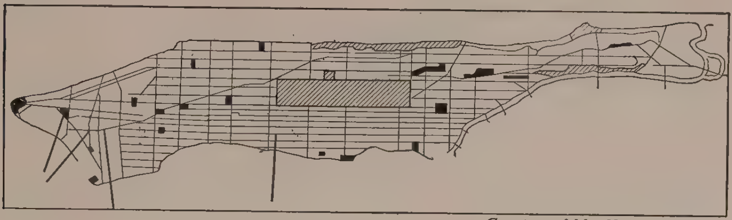
Many of the parks will be found on the outskirts of the larger cities, since places which still retain their natural beauty can only be found in such localities. To accommodate different sections of the city and to allow for future growth several such parks should be developed or at least the reservation of land should be made for this purpose. The different parks may be connected by boulevards and drives, which, if designed in the proper manner and with proper æsthetic effect, really become a part of the parks themselves.

The design of the system, therefore, is not extremely difficult. The parks are fixed points to be connected by the system. Distance, alignment, and grade are not of so much importance as in the case of a highway taking both a pleasure and a commercial traffic. Particular emphasis should be given to the æsthetic possibilities of the highways. This may sometimes involve entirely new layouts, such as roads along the banks of a river, the seashore, or across some area the natural environment of which is especially beautiful.

City Highways. The streets in the older portions of many large cities have practically the same lines today as in the first years of the cities' development. As the cities grew, the need for some systematic plan of street development was realized. The result is that in the older portions of some cities the streets will be found to be tortuous and narrow, while in the more recently developed portions, the evidence of a systematic plan is apparent.

A street plan is not well designed unless the plan is made to fit the topography and the drainage is taken care of. Topographical conditions will sometimes preclude the use of a uniform rectangular system if easy grades are to be obtained. The history of the growth and development of the large cities should be carefully studied, since it is only from these examples that we can predict with any assurance what future conditions may impose. A suburb at the present time may in a few years become an important part of the city and the street plan should be designed on such comprehensive lines that this possibility is provided for.

The Rectangular Plan. The rectangular block system, of which New York City is a good example, has been used in many cities where topographical conditions would permit. (See Fig. 15.) Such a system, however, if entirely devoid of diagonal streets cutting across the rectangular plan, does not accommodate the traffic to the best advantage and renders very little opportunity to improve the appearance of a city. Diagonal streets radiating from the city center to large public squares and from thence to the outskirts enable the traffic to move from one part of the city to another with the greatest despatch and tend to relieve the congestion of traffic that might otherwise occur.



Courtesy of Mr. Nelson P. Lewis.

FIG. 15. Street Plan of New York City.

The squares and centers afford a location for the erection of beautiful public buildings, the diagonal streets leading into the square making a fitting approach to such structures. It is a misfortune that the beautiful public library of New York City is hidden by its surroundings. Anyone can realize how much more the inherent artistic merit of this building would be appreciated if it were located in a large square so that it could be seen on approaching the square from several directions. The present plan of the streets of Washington, D. C., shown in Fig. 16, was designed by L'Enfant many years ago. It serves its purpose in an admirable manner today and has given Washington the enviable reputation of having one of the best and most comprehensive street plans of any city in the United States.

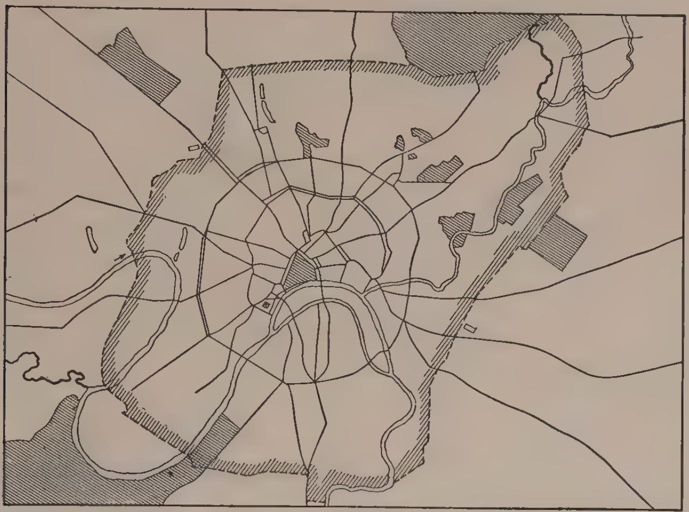
The Circumferential Plan. The systems of many European cities, which are pointed to as examples of what a comprehensive street plan should be, besides having a rectangular plan intercepted by diagonal streets, have so-called circumferential streets

From Baker's "Roads and Pavements."

FIG. 16. Street Plan of Washington, D.C.

which roughly encircle the city. This is well illustrated by the street plans of such cities as Berlin, Vienna, Paris, and Moscow. (See Fig. 17.)

Size of Blocks. The size of blocks is quite variable in the different cities of the United States. The blocks should be made rectangular and, in business districts, with the longest side parallel to the direction of the greatest travel. The frequency of cross streets parallel to the other side of the rectangle is determined by the amount of traffic which travels in this direction. The size of the blocks in the business and residential



Courtesy of Mr. Nelson P. Lewis.

FIG. 17. Street Plan of Moscow.

parts of a city is not necessarily the same since more frequent cross streets are needed in the former than in the latter. In business districts an alley should be provided from 15 to 25 feet wide running lengthwise through the middle of the block. Since experience has proved that the most convenient depth of a lot for either business or residential districts is from 100 to 150 feet, the total width of the block is made from 215 to 325 feet. In Boston the blocks are 125 to 252 feet wide and from 200 to 700 feet long; typical blocks in New York City are 200

by 900 feet and 200 by 400 feet; in Washington typical sizes are 400 by 600 feet and 300 by 800 feet.

Traffic. Traffic is a factor in street design that affects the width, grade, crown, foundation, and type of surface. The character of the traffic has undergone a marked change during the past fifteen years due to the increased use of motor vehicles. The horse-drawn vehicle must not only be provided for, but also the surface must be designed in some cases to take the swiftly moving motor car travelling at speeds of from thirty to sixty miles an hour. The use of motor trucks carrying loads of from 1 to 12 tons on four wheels is increasing by rapid strides.

Effect of Motor Car Traffic. The theory that the destructive force of the motor car travelling at high speeds is due to the suction developed underneath the tires has never been substantiated. That there is some suction at this point cannot be disputed. The main destructive effect, however, is produced by the driving wheels. This fact was clearly proved by some experiments which were made by the United States Office of Public Roads. An automobile of the touring car type was driven along a road at varying speeds of from fifteen to seventy miles per hour. Instantaneous photographs were taken of the car during the experiments, from which is was decidedly obvious that the dust raised by the front wheels was of a small and practically uniform amount regardless of the speed of the car, while the dust underneath the back wheels increased in a marked degree with the speed.

The accepted theory is that the destructive agent is a shearing force developed between the wheel and the road, causing the wheel to act as a grindstone on the surface. This force is ever present while the car is in motion and increases with the speed of the car. It is also known that there is more or less slip to the driving wheels, since it has been found that in travelling a certain distance, the rear wheels revolve more times than the front, due to the fact that when the wheels leave the ground in passing over uneven places the engine races. The successive waves across the surface of many of the ordinary macadam roads, which are subjected to a heavy motor vehicle traffic, are without

doubt produced by this constant pounding action. As long as the motor cars travel in a straight line there is very little side slip unless the road is in a slippery condition. On curves, however, there is a terrific slew to the rear wheels which is very destructive if the car takes a curve at a high speed.

Effect of Traction Engines. In 1896 a committee of the House of Commons of England made a thorough investigation of the effect of traction engines on roads in connection with pending regulations governing this class of vehicles. An ordinary locomotive or traction engine was defined by law not to exceed 14 tons in weight and not to be used to draw more than three loaded wagons. This committee concluded from the evidence which it gathered that, in some places where the houses were of inferior construction or the weights carried were excessive, and particularly on granite paved streets, there might be some objection from the standpoint of vibration. On a highway where either the foundation was bad or the stone was of a poor grade, this kind of traffic caused excessive damage, not only rutting the road, but destroying the shape to such an extent as to require complete reconstruction. These effects were increased in times of frost or wet weather.

Effect of Commercial Motor Trucks. In 1904 a committee was appointed by the Local Government Board of England to investigate the working of the 1903 Motor Car Act. Evidence was presented to this committee by manufacturers and engineers relative to the construction and use of motor cars. A motor car was defined by law not to be under 3 tons in weight when used alone and not to be used for drawing more than one vehicle. Several instances were cited in the evidence where macadam roads were severely damaged by this class of traffic. On one road between the county boroughs of Blackburn and Preston thirty-eight cars were put in service, which made a total of about one hundred trips a day over the road. Within one month's time, the road which had been in excellent condition for horse-drawn traffic was completely cut through. J. A. Brodie, M. Inst. C. E., was of the opinion that if the foundation of the road was ample, very little trouble would ensue from

this class of traffic if the regulations as to tire widths and loads were complied with. As examples of ordinary loads in Liverpool, Mr. Brodie gave 12 tons as about the weight of an ordinary cotton lorry, and 30 tons as a daily load behind a traction engine. He also cited one instance where as much as 3,000 tons of material were drawn over the streets of Liverpool in 80- to 100-ton-loads.

The commercial motor truck is being rapidly adopted by many varying interests in the United States. At the beginning of 1911 over thirty thousand trucks had been sold. The sales of 1911 and 1912 will show a very marked increase over this figure. This kind of traffic is presenting a very serious problem which must be met in the construction of highways. The trucks which carry the lighter loads are equipped with either a solid smooth tire or a pneumatic tire, a twin tire fitted with rubber blocks, or a metal tire. The weights carried vary from 500 pounds to about 15 tons making the total weight in the neighborhood of 20 tons for the heaviest trucks, approximately two-thirds of which is carried by the rear axle. The heaviest cars are built to carry their loads at a speed of about fifteen miles per hour. It is apparent that this class of traffic presents conditions which our ordinary highways have not been built to withstand. In order to successfully combat the effect of these heavy loads, more attention must be paid to the construction of the foundations to support the loads, while the surface must be constructed to withstand the grinding action of the wheels.

Effect of Horse-Drawn Vehicles. The horse-drawn traffic presents some characteristics which are very interesting. The ordinary broken stone road, if built with the proper materials and properly maintained, will successfully withstand the conditions imposed by this class of traffic up to a tonnage life of 100,000 tons per yard of width. In cases where very heavy loads on narrow tires have been drawn over surfaces in a soft condition, it is not surprising to find that the surface has been cut through and totally destroyed. Every one is familiar with the so-called "horse path" frequently seen on the country highways, formed in the center of the road by the horses' feet.

This condition is often due to the use of a soft stone which, combined with a dry season, makes the surface readily susceptible to the disintegrating blows of the horses' hoofs.

In connection with certain types of surfaces constructed with bituminous materials the horse-drawn traffic has been noticed to be very destructive. For instance, in Massachusetts where the Highway Commission has adopted the application of a coat of heavy asphaltic oil and sand as a method of maintaining the broken stone roads, it has been proved in several instances that it is a failure where it is subjected to any large amount of heavily loaded horse-drawn vehicles.

A flush coat of bituminous material has been found necessary to preserve the surface of certain bituminous pavements constructed either by the penetration or mixing method, when the traffic is composed largely of horse-drawn vehicles.

Loads and Tire Widths. Some of the heavy loads which occur on the streets of New York City are given by Henry B. Seaman, M. Am. Soc. C. E.,* as follows:

Cables weighing 84 tons carried equally on four wheels, the truck weight adding 6 tons; girders weighing 65 tons carried mainly on 2 rear wheels of a long truck, the truck weight adding 2 tons for each pair of wheels; an automobile truck carrying 10 tons on four wheels, the weight of the truck adding 6 tons; a coal truck hauled by three horses will carry 7 tons, the truck will add 2½ tons; trucks which carry the Lidgerwood hoists take a load of 15 tons, the weight of the truck being 3 tons; the standard truck for general use, hauled by two horses, carries a load of 5 tons and weighs 2½ tons.

As early as 1823 regulations governing the allowable loads and width of tires for horse-drawn vehicles were included in the General Turnpike Act of England.

The following regulations relative to traction engines were prescribed in England in 1896: the maximum weight of a loaded trailer to be 8 tons, the minimum width of tires in this case to be 8 inches, with an amendment to the effect that a single trailer

* See "Proceedings," American Society of Civil Engineers, Dec. 1911.

might carry a single piece weighing over 16 tons, provided the width of tires is not less than 8 inches. Traction engines drawing trailers must have tires which are 2 inches wide for each ton of weight of the traction engine, unless the diameter of the wheel be over 5 feet, in which case the width of tire may be reduced in such proportions as the diameter is increased. The tires of the driving wheels may be shod with diagonal crossbars or with wooden blocks of certain approved design.

The 1904 Motor Car Order of England fixes the limit of weight of a loaded motor car at 12 tons and a loaded trailer at 8 tons. The width of tire depends upon the size of the wheel and the axle load, for a motor car the minimum width was fixed at 5 inches and for a trailer at 3 inches. These regulations, however, did not apply to tires which were pneumatic or made of a soft and elastic material. A distinction was also made relative to the speed of the cars depending upon the weight and the kind of tires. A maximum of 8 miles per hour was provided for motor cars exceeding 3 tons in weight, unladen, or with a registered axle weight laden exceeding 6 tons. The speed was reduced to 5 miles per hour in the case of cars drawing a trailer. The speed was increased to 12 miles an hour for cars equipped with pneumatic or other elastic tires, which did not have axle weights exceeding 6 tons, and was 8 miles per hour, when the axle weight exceeded 6 tons.

In order that horse-drawn vehicles should not damage the road it is recommended that the tire width be so regulated that it will not exceed 500 pounds per inch of tire width for a wheel 2 feet in diameter, allowing, however, an increase of 30 pounds per inch for each additional 3 inches of diameter. The maximum width of tire for this class of vehicles would be fixed at 6 inches. In the case of motor cars and traction engines the same regulations would hold except that the maximum width of tire would not be limited and the regulations would not apply to tires which are pneumatic or are made of a soft or elastic material.

The foregoing information relative to traffic and its regulation has been given to show the conditions which the highway must be designed to meet. State trunk highways and city streets

are certain to be subjected to such traffic. Although a traffic census will determine the present conditions, future development must be considered. The traffic to which the highways of a park system are subjected is generally restricted to pleasure vehicles alone.

Determination of Width. The determination of width for all classes of highways is of the utmost importance and should be given very careful consideration. The streets and roads should be classified with reference to the traffic that they take and a width should be chosen which will not only accommodate the present traffic, but also be sufficient to allow for a future increase in the traffic. In the case of city streets, provisions for light and air, room for subsurface structures, car tracks, as well as accommodations for the traffic of vehicles and pedestrians must be considered. The width of roads is based mainly upon the amount of vehicle traffic. In the case of park highways, conditions may be found similar to either those for city streets or for country highways and would be treated in the same way except that the proper æsthetic treatment of the highway may warrant using a width otherwise not justifiable.

Width of City Streets. In wholesale districts where the pedestrian travel is light, the sidewalk widths can be reduced and the width thus obtained put into the carriageway. A large commercial truck backed up against the curb will occupy a length of about 13½ feet. A truck on either side of the street in this position would therefore occupy 27 feet. The width out to out of the ordinary commercial motor truck is between 6 and 8 feet. To provide for the easy passage of two lines of vehicles between those backed up against the curbs would thus require an additional width of carriageway of about 17 feet, which would make the total width of carriageway about 44 feet.

For streets in retail business districts the pedestrian traffic is of more importance and the sidewalks should be given the full width.

In residential districts a carriageway of from 30 to 36 feet

is generally ample. Where a residential street is subjected to a light local traffic consisting principally of delivery teams, there is really no need for a carriageway wider than 20 feet. There are several advantages in favor of this smaller width. Assuming that the distance between property lines is 60 feet and a 20-foot carriageway is constructed, 40 feet is left available for sidewalks and parking spaces. Allowing a width of 12 feet for each sidewalk, a parking space could be constructed beyond the sidewalk on either side 8 feet in width. This space, if properly treated, would add greatly to the appearance of the street. By reducing the width of carriageway the first cost of construction and later maintenance costs are reduced by approximately one-third. The width of 20 feet is ample for two teams to pass or one to pass when the other is backed against the curb. The parking spaces would be available for the location of underground services, and thus frequent disturbances to the carriageway could be avoided.

Street widths are generally stated as the distance between property lines. The width taken by each sidewalk in city streets is from one-fourth to one-fifth the total distance between property lines although this may be reduced in some instances. The widths of streets in several cities is given by J. Nolen* as follows:

Class	London	Leipzig and Frankfort	Berlin	Washington, D. C.
Main...........	100–140 ft.	85–118 ft.	95 ft. or more	160 ft.
Second Class....	60– 80 "	50– 80 "	65–95 "	120 "
Local...........	40– 50 "	35– 47 "	40–65 "	60–90 "

General data relative to average street widths in various American cities follow: New York, streets, 60 feet, avenues, 80 feet; Philadelphia, intermediate streets, 40 feet, principal streets, 60 to 100 feet; St. Louis, 50 to 100 feet; Boston, 40 feet, 50 to 80 feet on important avenues; Baltimore, 66 feet; San Francisco, 68 feet 9 inches; Cincinnati, 40 to 100 feet, averaging 50 feet; Milwaukee, 60 to 66 feet, 70 to 80 feet. In building new streets

*See "Municipal Journal and Engineer," June 7, 1911.

in the Borough of The Bronx, New York, the following street widths and carriageways are prescribed:

Streets	40	feet wide,	20	foot	roadway.
"	50	" "	24	"	"
"	60	" "	30	"	"
"	70	" "	34	"	"
"	80	" "	42	"	"
"	100	" "	60	"	"
"	120	" "	76	"	"

The widths, however, are affected by the existence of street railway tracks.

The New York City ordinance governing the width of streets is as follows:

"For streets less than 20 feet wide and used for vehicular traffic, the width of the roadway shall correspond with the street width, less the space occupied by the curb.

"For streets having a width ranging from 20 to 50 feet and not occupied by a railroad, the width of the roadway shall be 60 percent of the total of the streets.

"For streets having a width ranging from 50 to 60 feet, and not occupied by a double track railroad, the roadway shall have a width of 30 feet.

"For streets having a width ranging from 60 to 66 feet 8 inches and not occupied by a double track railroad, the width of the roadway shall be one-half of the total width of the street.

"For all streets having a width of over 66 feet 8 inches, except those portions of Fifth Avenue and of Forty-Second Street, Borough of Manhattan, concerning the treatment of which a resolution was adopted by this Board on December 18, 1908, the roadway width shall be 80 percent of the street width less 20 feet; provided, however, that if the street is occupied by a double track railroad the minimum roadway width herein prescribed for such a railroad shall be required.

"For streets in which there is a single track railroad, the minimum roadway width is to be 30 feet.

"For streets in which there is a double track railroad, the minimum roadway width is to be 40 feet.

"The roadway shall be centrally located between the street lines, and for streets having a width of 20 feet or more the remaining space on each side of the roadway shall be designated as the sidewalk."

In very remote streets or alleys, if there is a possibility of providing for two vehicles to pass each other, this should be accomplished even if the sidewalks have to be entirely sacrificed. If, on the other hand, the width of carriageway is only sufficient for one vehicle, the sidewalks should occupy all of the width over and above that necessary for the passage of one vehicle.

Width as Affected by Car Tracks. The location of the car tracks in the carriageway is disadvantageous from several standpoints. Wherever possible it is best to provide a trackway for cars which is separated from the carriageway by a barrier or parking space. Certain streets might have sufficient width so that this plan could be conveniently carried out. Where trackways have to be built within the limits of the carriageway, the width of the street will determine whether it is best to locate them at the sides of the street or to put them in the center. This subject is considered in detail in Chapter XXII. A great deal of the passenger traffic in the future may be carried on motorbuses. The use of this type of public conveyance will eliminate the car tracks from the carriageway.

Width as Affected by Subsurface Structures. Ample provision must be made for the location of subsurface structures. In business districts these structures become very much congested. Sewers, water and gas pipes, conduits for telegraph and telephone wires, steam and hot water pipes, refrigerating pipes, and tunnels are commonly found in our largest cities. The space underneath the sidewalks from the property line to the curb line and extending to the sidewalk level in many streets of the business districts of American cities is utilized as a vault by the property owner. This prevents using the sidewalk width for the accommodation of subsurface structures and makes it necessary to place them within the carriageway. In 1902 a law was passed in Philadelphia requiring the top of such vaults to be at least 4 feet below the grade of the sidewalk, this space

being intended for the use of pipe services. It is evident that the interests of the roadway will be best served by eliminating from it all pipes which are liable to be disturbed to any extent. The expense entailed in constructing pipe galleries on either side of the street for the accommodation of these structures is so great that it becomes prohibitive except in very special cases. Further space will not be devoted to this topic here, since the location of the different subsurface structures is considered in detail in Chapter XXIII.

Width of Roads. Roads which only take a horse-drawn vehicle traffic can be made narrower than those which are subjected to both horse-drawn and motor car traffic. In the former case a width of 14 to 16 feet gives sufficient clearance between two passing teams. The width out to out of the average touring car is about 6 feet, while motor trucks are made as wide as 8 feet. A wider road is required than for the horse-drawn vehicle traffic in order to allow the machines to pass each other at a fair rate of speed with the proper clearance and still keep on the improved surface. Many instances have been observed where a 14-foot width of macadam has not been sufficient to prevent the automobiles in passing each other from working off the edge of the macadam into the earth shoulder of the road so that ultimately the edge of the road metal has been left exposed and later broken down. On curves this same condition exists and to a marked degree on sharp curves. For interstate and intrastate highways a width of improved surface of 18 to 20 feet would probably be none too great, while a width of 14 to 16 feet would be ample for those roads which act as feeders to the classes just mentioned, the smaller width to be used only in case of a very light traffic. In England the main roads are made from 16 to 22 feet wide, and the national roads in France are made 23 feet wide.

There are many existing roads which have a right of way a great deal wider than is necessary, in some cases it is as much as 160 feet. In acquiring a strip of land for a new location a width of 30 feet on either side of the center line is ordinarily sufficient. On roads the shoulders make a suitable place for the location of

pipes. There are places, however, where the pipes will have to be located within the carriageway. In such a case the best location of either the water or gas pipes is at one side of the road so that work incident to these services will not interfere with the traffic. Sewers are generally located in the middle of the road.

Width of Park Highways. The same general principles set forth relative to the width of streets and roads apply to the highways of parks. It has been previously mentioned, however,

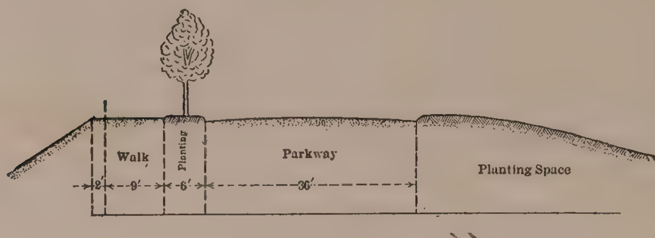


Fig. 18. Typical Section of Park Highway. Massachusetts Metropolitan Park Commission.

that the width adopted is also affected by the consideration of æsthetics. There is no set of rules which can be given covering the relation of width to æsthetics since the problem is one largely influenced by local conditions. Many Park Commissions, however, have adopted standard widths to be used under different conditions. Some of the typical sections showing the widths as built by the Massachusetts Metropolitan Park Commission are given in Figs. 18 and 19.

Determination of Grade. The next step in the design after proper consideration has been given to the requisite width is the determination of the grade. According to theory the maximum grade allowable is the one over which the greatest loads expected can be hauled at the least expense. In practice, however, the maximum grade is also governed by other factors than the loads to be hauled and in many places a maximum rate of grade is established, which is never exceeded except when the

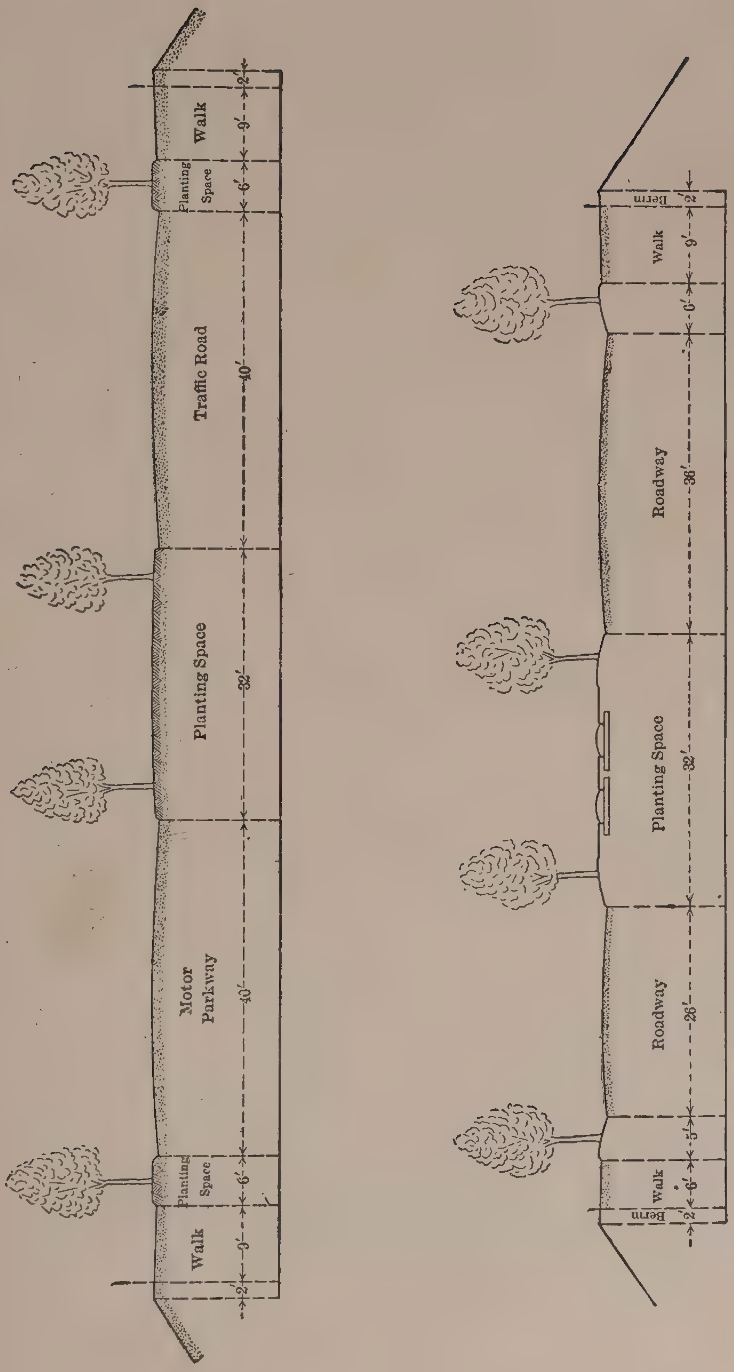


FIG. 19. Typical Sections of Park Highways. Massachusetts Metropolitan Park Commission.

environments and the consideration of cost make it advisable to use a steeper grade. The grade should be adjusted to suit the character of the road surface that is going to be used or *vice versa*. Apparently all classes of motor vehicles are so designed that they can climb without difficulty practically any grade which would be built for horse-drawn vehicles, hence only horse-drawn vehicles have to be considered.

It has been proved by actual test that a horse can exert a pull of 120 pounds when working steadily and that for a short period this pull may be increased to practically 500 pounds. As the grade increases the load a horse can pull decreases very rapidly. For instance, on a 6 percent grade a horse can readily pull only about one-half as much as on the level; on a 10-percent grade only one-fourth as much. It is evident that it would be better, if possible, to arrange the grade line so that the maximum grades will be down hill grades in the direction in which the maximum loads are hauled. Topographical and other considerations, however, sometimes make it impossible to obtain such an arrangement.

Whether the grade is being designed for a street or a road, it must be established so as not to cause damage to the surrounding property and so as to best accommodate intersecting streets or roads. The grade must be established so that proper drainage and proper foundation can be obtained. In the case of roads, particularly, it is frequently necessary to considerably raise the existing grade in order to obtain a satisfactory bottom underneath the road. Again a considerable saving may be affected by taking advantage of an old surface as a foundation, the new grade being established so as to disturb the old road as little as possible. It will frequently be found that it is desirable to approximately follow the grades of existing tracks along the road.

Although it is of considerable advantage to obtain a grade which will make the cuts and fills balance, or in other words preclude the necessity of any borrow on the work, still it is obvious that many times other considerations are of far greater importance. The economy of balancing cuts and fills can only be ascertained by comparing the cost of possible overhaul, in

moving the earth from one point on the road to another, with the cost of borrow at some nearer point.

Frequently it is possible to use grades on a road having frequent curves, due to the fact that the curves break the view, which otherwise would give the road an objectionable appearance. Vertical curves at changes of grade and the grades at intersecting streets must be carefully worked out in order to obtain a result that will be satisfactory both from the standpoint of use and appearance.

Maximum Grades. Grades as high as 20 percent and more are found in mountainous districts, whereas many of the State Highway Departments never use grades over 7 percent. Within the cities the grades follow quite closely the general topography of the earth's surface and hence the problem in this case is to provide a surface that will be suitable to the traffic.

S. C. Thompson, M. Am. Soc. C. E., in speaking of the grade limitations of pavements in the Borough of The Bronx, New York City, said in part:

"The grade of sheet asphalt is usually limited to 3 percent, and such a street requires no sanding. Sheet asphalt has been laid on 4 percent grades, but it is slippery when wet or frosty. The grade of wood block should not exceed 3 percent. Wherever an excessive amount of oil per cubic foot has been used in treating the blocks, the surface is slippery even on slight gradients. The grade of asphalt block should not exceed 6 percent and up to this inclination answers the purpose intended very satisfactorily. The steepest grade at present on which block asphalt has been used is 7 percent. Vitrified bricks are satisfactory on grades not over 4 or 5 percent, as far as gradients are concerned. The maximum grade on which vitrified brick has been used is 5 percent. Iron slag is laid on grades up to 11 percent, but this has not been favored by teamsters. Granite block is laid on nearly all street gradients; has been used on grades as high as 13 percent. Medina sandstone is very satisfactory on grades and comes nearer the physical requirements for stone block pavement on grades than most other kinds of pavements. The maximum grade on which Medina sandstone has been used is 5.5 percent."

There are several examples in other cities where these different types of pavements have been used on much steeper grades. For instance, sheet asphalt has been laid on grades of 7 percent, and in Pittsburg, Pa., on a grade of 17 percent; brick pavements have been used on streets having grades varying from 8 to 15 percent; in London wood blocks have been used on streets with grades as high as 8 percent, although it is usually considered that 4 percent is the limiting grade for this type of pavement.

The limiting grades for highways constructed with a bituminous surface of bituminous macadam or of bituminous concrete will depend to a great extent upon the method of construction and the character of the material employed. In some cases the mosaic surface of the stone in the upper course will be exposed and a good foothold obtained. When a flush coat is applied of certain bituminous materials it becomes so smooth and hard that a very poor foothold is furnished and the pavement is as slippery as sheet asphalt. On the other hand there are materials which may be used for a flush coat or for the construction of a bituminous surface which never becomes so hard as to make the pavement dangerously slippery except on excessive grades.

Minimum Grades. As a general rule the smoother a road surface the lower the rate of grade which may be considered the minimum. The following minimum grades for broken stone roads have been used: in England, 1 in 80 or 1¼ percent; in France, 1 in 125 or 0.8 percent; in the United States, 1 in 200 or 0.5 percent. If the surface of a broken stone road is well maintained and a good fall is given to the ditches at the side, there is no reason why a perfectly flat grade cannot be used for a short length.

The minimum grade of streets is important from the standpoint of drainage. It is possible in flat places to make the curbs level and to obtain the grade by increasing the depth from the gutter to the top of the curb. The longitudinal grade in this instance will fall from a summit in either direction for a distance of 100 or 200 feet. The depth of the curb at the summit might be 4 inches and at the low point as much as 10 inches, which would make a fall of 6 inches or a 0.5 percent grade in a dis-

tance of 100 feet. Catch-basins would be built at the low points. If streets are swept or flushed every day a fall of 3 inches in 100 feet may be adopted.

Drawing the Grade. The ground line of the profile should be carefully studied and certain limiting points on the grade line may be established by giving attention to the considerations enumerated above. Grade lines can then be drawn in between these points by trial until a final grade is determined which will best fit the conditions.

On roads it is customary to change the grade at some station which is a multiple of 50 or 100 feet and by so doing it is an easy matter to adjust the elevations so as to obtain a rate of grade

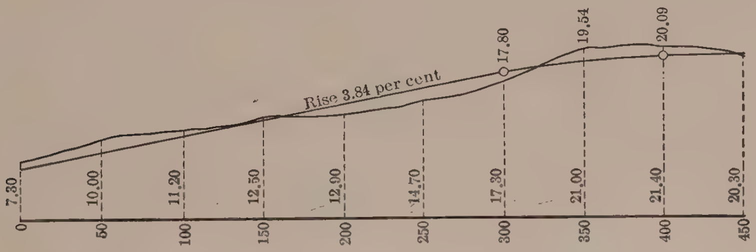


FIG. 20. Sketch Showing Representation of Finished Grade Line.

divisible by two. This is purely a matter of convenience, however, in that it facilitates the grade computations when the grade has to be figured for every 50-foot station.

The grade is shown on the drawing on the profile only. Elevations are written for all stations of vertical curves and for all points denoting a change of grade. The rates of grade are written along the grade line where it is uniform for a distance of 100 feet or more. Fig. 20 shows the original ground line and the finished grade line and represents one method of recording the grade on the plan.

On streets it is customary to make the grade a straight line between the intersecting streets unless a perfectly flat grade would ensue, in which case it is broken to provide for drainage. This is a general principle but the topography may prevent its adoption in some cases. Furthermore it will some-

times be necessary to make slight changes in the grade for the grade table, formed by the intersecting streets, in order to provide an intersection that will not only look well, but will take care of the water and be safe to use. The grade of the street is recorded on the drawings. Due to the fact that the grade points come at odd stations the grade rates have to be figured frequently to the nearest thousandth. The grades for streets should be established and recorded so that the proper grade can be given for new buildings and other structures which may be built in advance of the street improvement.

Vertical Curves. In order to avoid the abrupt transition from one grade to another, a vertical curve is put in at the grade intersections, the length of which will depend upon the rates of the grades. The parabola is the form of curve which is most

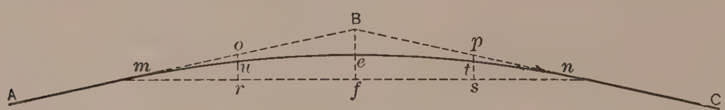


Fig. 21. Vertical Curve.

generally used. In Fig. 21, two intersecting grades are shown by the lines $A\,B$ and $B\,C$. It will be assumed that the curve is to be 200 feet long, and that it will be staked out on 50-foot stations. The equation of the parabola is $y^2 = 2\,p\,x$, x and y being the abscissa and ordinate respectively of any point on the curve. This equation simply means that the abscissas of points on the curve vary as the squares of the distances from the origin. The curve is tangent to the two grades at m and n. Draw the chord $m\,n$. Theoretically y distances should be measured along $m\,n$ and x distances perpendicular to this line. Assume for the moment that the lines $o\,r$, $B\,f$, $p\,s$ are so drawn. One of the properties of the parabola is that the vertex lies half way between B and f, if $B\,f$ is perpendicular to $m\,n$, hence the point e may be located. At the points r and s which are half way between f and m and f and n respectively, the ordinates to the curve $r\,u$ and $s\,t$ are $e\,f - \frac{1}{4}$ of $e\,f$, because the x distances measured in this case perpendicular to $m\,n$ vary as the square of the y's and

$y = \frac{1}{2}$. Other points can be found on the curve in a similar manner, y always being the fractional part of $f\,m$ or $f\,n$ measured from m and n respectively. Since the curve is symmetrical about the line, $B\,f$, it is only necessary to make the computations for one side of the curve. In practice the lines $o\,r$, $B\,f$, $p\,s$, etc., are not perpendicular to the line $m\,n$, but are vertical. The error involved, however, in scaling on these vertical lines the theoretical computed distances to points on the curve is negligible.

The length of the curve varies depending upon the algebraic difference in rates of the intersecting grades. Based on 50-foot stations, curves with lengths as given for the following conditions have been found to work satisfactorily.

Three stations (100 feet), when the algebraic difference is between 1.0 and 3.0.

Five stations (200 feet), when the algebraic difference is between 3.0 and 6.0.

Seven stations (300 feet), when the algebraic difference is more than 6.0.

Design of Street Intersections. The adjustment of grades at street intersections is sometimes a very troublesome problem. The grade usually required to be established by ordinance is that of the center of the street. In order to avoid confusion the grade of the curb corners or of the property corners should also be established. An examination of Fig. 22 will plainly show that if only the elevation of the intersecting centers of streets is established there are two elevations for each curb corner and for each property corner at the intersection.

For instance suppose street A, having a falling 6 percent grade, to be intersected by street B, which has a falling 3 percent grade. Assume that the elevation common to both grades on the center lines of streets is 100. The elevations given by the grades of the two streets at the curb corners have been written on the figure. The maximum difference it will be noticed is about 1.55 feet for the same curb corner. Even if the elevation of the curb is determined upon, the same confusion will arise in fixing the elevation for the property corners, if the curbs are on grades of any perceptible amount. The difficulties which may

confront any one when only one elevation of the intersecting grades is established is apparent.

Although it is generally possible to flatten out the grade of a street on approaching an intersection, particularly in the case of streets having steep grades, this may not be the most advisable thing to do since it increases the rate of grade considerably for the remaining length of the street. Under certain conditions it may be possible to make the four curb corners the same eleva-

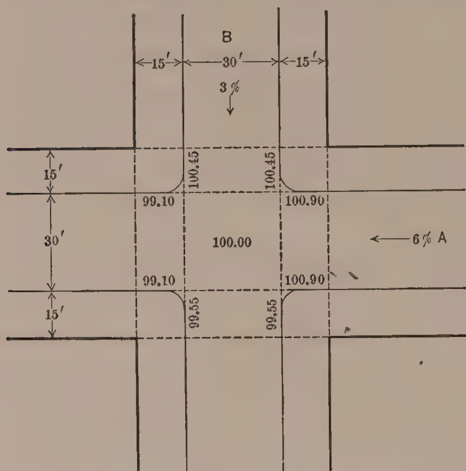


FIG. 22. Elevations at Curb Corners from Intersecting Grades.

tion and the four property corners the same elevation, but different from that of the curbs, the area bounded by the four curb lines being crowned so that the high point is at the intersection of the center lines of streets.

The following is taken from an article* based on the report of Rudolph Hering, M. Am. Soc. C. E., and Andrew Rosewater relative to the improvement of street intersections in Duluth, Minn: "Upon all streets and avenues in the city, except in the business section, the curb grades should be unbroken between intersecting curbs. In the business section of the city the lines of curb grades, when exceeding 3 percent, should be broken

* See "Engineering News," Feb. 14, 1891.

at the street or property line. All street crossings from the curb on one side to the curb on the other, irrespective of location, should be designed on the basis of a 3 percent slope, except when the slope of the intersecting streets or avenues is less, in which case the grades shall be continued unbroken over the crossings. In determining the height of block corners the elevation of the curbs at the two opposite points should be added to the rise of the two walks from their respective curbs to the corner, on the basis of 2½ percent inclinations, which sum divided by 2 will give the desired elevation. In other words the block corner shall have an average of the elevations determined from the two opposite curbs after allowing the usual rise in the walks of ¼ inch per foot across their width."

In a paper presented before the Municipal Engineers of New York City, V. S. Moon, Assistant Engineer, Board of Estimate and Apportionment, proposed the following rule governing street grades:

"1. *Definition of Platforms.* The center line intersection shall be deemed to be the point of intersection of the center lines, except for cases where the center lines do not meet at a common point, when it shall be the area included within the center lines at their intersection, shown as point *c* and area *c c c* in Figs. 23 and 24.

"The Curb Line Platform shall be deemed to comprise the area included within the lines connecting the points of intersection of the curb tangents, or in the case of a street terminating at another street it shall comprise the area within the prolongations of the curb lines across the intersection and a line joining the curb tangents, shown as area *a a a a* in Figs. 23 and 24.

"The Building Line Platform for rectangular intersections shall be deemed to include the area bounded by the prolongations of the building lines of both streets across the intersection so as to comprise the greatest platform area. In the case of other than right-angled intersections, it shall comprise the area bounded by the respective lines of each street and by lines at right angles or normal to the center lines and passing through acute-angled building line corners, or the corners giving the greatest platform

area. If the intersection of the center lines falls without the Building Line Platform, as above described, the said platform shall be increased sufficiently to include the said intersection. When the building line corner is turned with a curve the platforms above defined shall be indicated upon the map unless herein definitely fixed. The Building Line Platform is defined by the lines *A–A*, in Figs. 23 and 24.

"2. *Definitions of Elevations Fixing Grades.* Unless otherwise indicated on the map, the elevations shown at a street

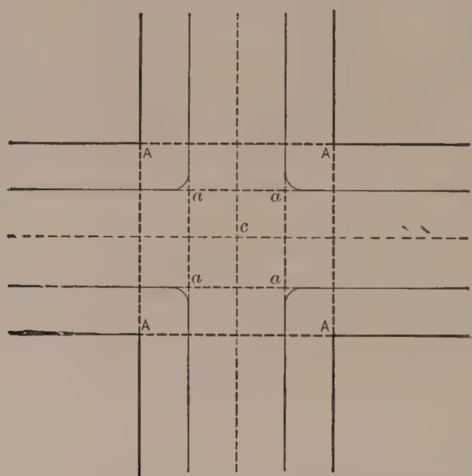


FIG. 23. Sketch Showing Curb Line and Building Line Platforms.

intersection shall be deemed to be that fixed for the point of intersection of the center lines of both streets affected, or for the Center Line Intersection.

"3. *Treatment of Center Line Intersection.* The Center Line Intersection, when it comprises an appreciable area and unless otherwise shown on the map, shall have a uniform elevation at its boundaries, and in determining the elevations for the other platforms herein described, the Center Line Intersection referred to as a basis of calculation shall be deemed to bė the nearest point on the center line of each street at the boundary of the said platform.

"4. *Treatment of Platform for Streets Having a Light Grade.* If the grade of each of the intersecting streets is 3 percent or less, as determined by calculating the rate between the established elevations, the elevation of the center lines of each street within the limits of the Curb Line Platform shall be the same as that fixed for the Center Line Intersection. The elevation of

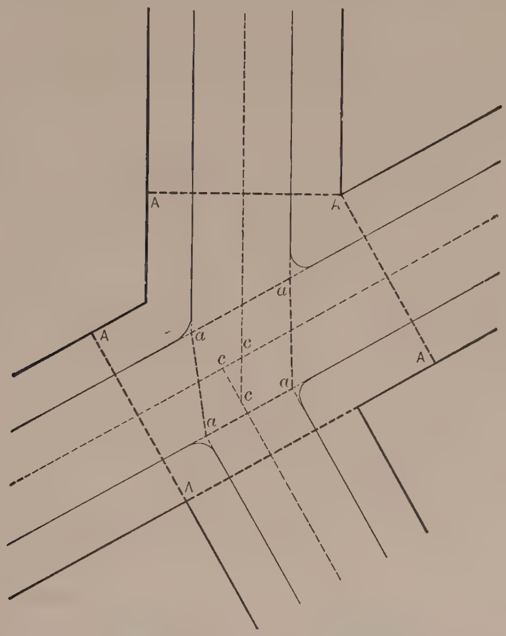


FIG. 24. Sketch Showing Curb Line and Building Line Platforms.

the curbs shall be determined as indicated in Paragraph 8. Provided, however, that the difference in the elevation of points on the center lines opposite any building line corner shall not provide a greater transverse sidewalk slope than that fixed as the maximum in Paragraph 7, in which latter event the Building Line Platform shall be used and the grades of that portion of the streets adjoining the said corners shall be flattened between the boundaries of the Building Line Platform and the Center Line Intersection, as provided in Paragraph 5 (a).

"5. *Treatment of Platform for Streets Having a Steep Grade or Meeting at an Acute-angled Intersection.* (*a*) If the grade of

any portion or portions of intersecting streets adjoining a building line corner is over 3 percent, as calculated between the established elevations, or if a further flattening of the platform grade is required to provide proper sidewalk slopes, for any part of an intersection described in Paragraph 4, the grades of the said portion or portions of each street shall be reduced between the boundaries of the Building Line Platform and the Center Line Intersection as follows: If the intersecting streets are of the same width, the grade of the street traversing the shorter block length adjoining the intersection shall be reduced one-third and that of the street traversing the longer block shall be reduced two-thirds. In case the streets have different widths, the grade of the wider street shall be reduced one-third and that of the narrower street two-thirds between the above limits. All grades less than 3 percent, which are not herein required to be flattened, shall be applied at the same rate as originally computed between established elevations. Provided, that in no case shall the maximum platform and sidewalk slopes fixed in Paragraphs 6 and 7 be exceeded.

"Any excess in grade over that allowed in Paragraph 7 shall be removed by further flattening, as follows:

"(*b*) Special flattening of platform grades for extreme cases of steep grades of acute-angled intersections. If the difference in elevation tentatively fixed for points on the center lines of intersecting streets opposite any building line corner, after applying the minimum and up to the maximum transverse sidewalk slope on the higher and lower sides respectively, exceeds the maximum transverse sidewalk grades hereinbefore described, the elevation of each street at the boundary of the Building Line Platform shall be adjusted to remove the excess, the adjustment of each of the said elevations being directly proportional to the grade of each as originally flattened or applied.

"For all cases covered by Paragraphs (*a*) and (*b*) the elevations at the intersections of the center line of each of the narrower streets or at the streets traversing the longer blocks, if they are of equal width, with the Curb Line Platform of the intersected street shall be the same as the elevation of a point on the center

line of the intersected street immediately opposite the first named intersection, except that the elevation at this point shall be abandoned when the grade along the center line between the Curb Line Platform and the Building Line Platform exceeds the grade as originally computed.

"The grades of the center line of the wider street or of the street traversing the shorter block, if they are of equal width, shall be uniform between the exterior boundaries of the Building Line Platform and the Center Line Intersection, except that the maximum platform slope hereinafter fixed shall not be exceeded. The grades of the center line of the narrower street or of the street traversing the longer block, if they are of equal width, shall be uniform between the elevations fixed at the exterior boundaries of the Building Line Platform and those fixed at the boundaries of the Curb Line Platform, and also between the latter point and the Center Line Intersection.

"6. *Maximum Platform Grades.* The maximum allowable grade along the center line between the Curb Line Platform and the Center Line Intersection shall be at the rate of 4 percent unless otherwise indicated on the map.

"The grades along the center line between the elevations established within the limits of a Building Line Platform shall be uniform, subject only to the flattening provided for in Paragraph 5 (*b*).

"7. *Transverse Sidewalk Grades.* Whenever practicable, the sidewalk shall slope upwards in a direction at right angles to the curb toward the building line at the rate of 2 percent.

"The elevation of the sidewalk at the building line corner shall be determined by applying this rate to the elevation of the curb, giving the higher building line elevation, at a point immediately opposite the corner, unless the resulting grade on the lower side exceeds 6 percent, in which case the sidewalk shall be level on the higher side and a greater transverse sidewalk slope up to the maximum shall be used on the lower side

"The maximum transverse sidewalk slope shall be 6 percent, except in those cases where the street grade is originally computed on any street adjoining a building line corner is more

than 6 percent, when the maximum slope shall be 10 percent for either street, opposite the said corner. In no case shall the sidewalk at the building line be lower than that of a point immediately opposite it on the curb.

"If the transverse sidewalk slope at the building line corner is more or less than 2 percent, it shall be made to agree with this latter rate at a point distant 25 feet from the building line corner.

"8. *Curb Elevations.* The relation between the elevation of the center lines and of the top of the curbs at points immediately opposite at the boundary of and outwardly from the Building Line Platform shall be as follows: For roadway widths of 24 feet or less the top of the curbs shall be 0.1 of a foot higher than the center line. For roadway widths ranging from 24 feet up to and including 34 feet, the top of the curbs and the center line shall be at the same elevation. For roadway widths ranging from 34 feet up to and including 44 feet, the top of the curbs shall be 0.1 of a foot lower than the center line. For roadway widths ranging from 44 feet up to and including 54 feet the top of the curbs shall be 0.2 of a foot lower than the center line, and for roadway widths ranging from 54 feet up to and including 64 feet, the top of the curbs shall be 0.3 of a foot lower than the center line.

"The elevation of the intersection of the curb tangents shall be determined from a point immediately opposite on the center line of the wider street or the street traversing the shorter block, if they are of equal width, subject, however, to the same correction in elevation between the top of the curbs and the center line as herein provided.

"9. *Depth of Gutters.* Whenever practicable a standard depth of gutter of 0.4 of a foot shall be used.

"10. *Curb Grades at Corners.* The tangents in the curbs shall be graded uniformly between the elevations established for them at the boundaries of the Building Line Platform and at the intersection of the curb tangents. The curve formed in the curb joining the tangents shall follow a uniform grade between the elevations of the curb tangents at the points of curve.

"11. *Grades Between Platforms.* The grades of the center line and of the curbs between the elevations computed at platform intersections, or between a platform and an intermediate established elevation, shall be uniform."

Curves. In the design of roads, the elimination or flattening of sharp curves is desirable. The speed of horse-drawn vehicles is not great enough to be dangerous at curves or to cause excessive wear at these points. The proper radius of curve would depend in this case principally upon the length of the team and wagon and the width of the road, and it has been found that to permit a four-horse team and vehicle about fifty feet in length to keep upon a 12-foot roadway requires a curve having an inside radius of about 100 feet. This radius decreases as the road width increases so that on an 18-foot roadway, the inside radius necessary is about sixty-six feet. The practice in France is to use a radius of 165 feet for the national roads which are 32 feet wide and in extreme cases 100 feet; a radius of 50 feet is used on principal country roads which are 20 feet wide.

In designing a road that takes either motor car traffic alone or a combination of motor car and horse-drawn vehicle traffic, the safety of the traveling public must be considered. Sharp curves are points at which collisions are very liable to occur, particularly if the view is obstructed. Sometimes, if it is impossible to increase the radius of the curve, a great improvement can be obtained by clearing away obstructions so that the curve can be seen throughout its entire length when approached in any direction. Besides the danger of collision, excessive wear takes place on curves subjected to much motor car traffic. It is natural for all traffic to keep to the inside of the curve and in the case of the motor vehicles, if the speed is not brought down to about ten or fifteen miles an hour, the slew of the vehicles as they pass around the curve tends to grind out the road material. The conclusion adopted by the First International Road Congress relative to the minimum radius of curves is as follows: "The radii of curves should be as great as possible, 164 feet at least, the curves being connected with the tangents by parabolic arcs; the outside of curves should be slightly raised but so as

not to inconvenience ordinary vehicles, no obstructions to the view should be allowed at the curves. A narrow sidewalk,

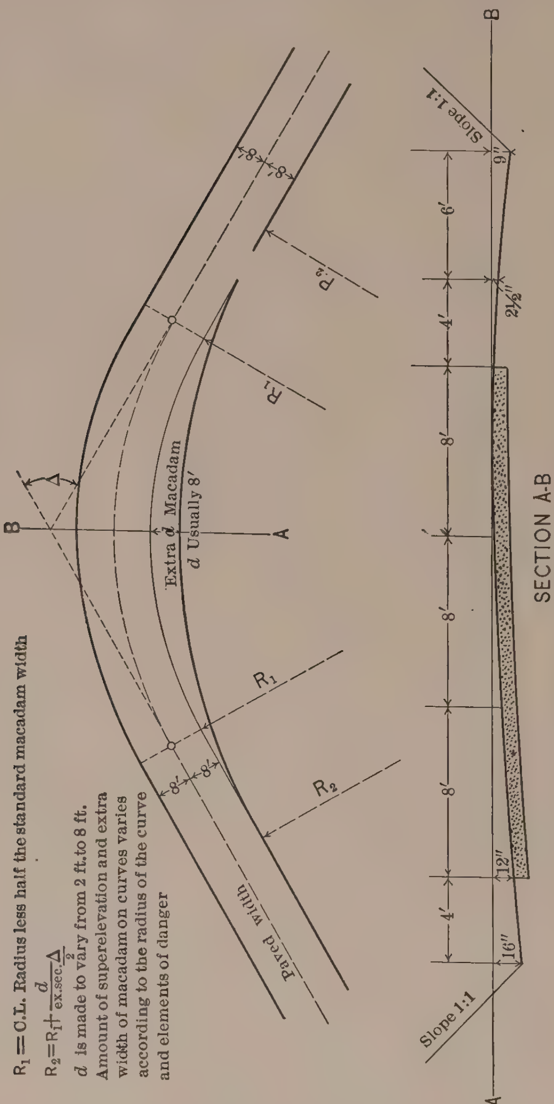


FIG. 25. Sketch Showing Widening of Macadam Roads on Curves. Los Angeles County Highway Commission.

bounded by a curb, should be laid on the side of the shorter radius and the depositing of heaps of material should be for-

bidden." Fig. 25 is a typical layout showing the widening of a macadam road at curves as adopted by the Los Angeles County Highway Commission in 1910.

Sharp curves on streets are unavoidable since a rectangular block system always forms a large part of a city's street plan. The radii of the curves at the corners of streets will generally vary from about 4 to 12 feet, depending upon the width of street and the angle included between the curb lines. On wide streets the smaller radii can be used, whereas on streets of the minimum width the corners should have the larger radii if possible, in order to better accommodate vehicular traffic entering the street. A radius of 8 to 10 feet works out very satisfactorily. At streets which intersect at other than right angles and at the intersections of curved streets, the curbs will have to be cut to fit the special curves which will ensue in working up the street lines.

The New York City ordinance requires that the curb corners at street intersections, where the interior angle is 30 degrees or more, shall be turned with a curve having a radius of 5, 6, 8, 10 or 12 feet, this being determined for each case as the nearest of these dimensions which would represent 10 percent of the width of the wider street, provided, however, that in case the interior angle is less than 80 degrees, the radius shall not be less than 20 percent of the distance between the building line corner and the point of intersection of the curb tangents. For intersections where the interior angle is less than 30 degrees a tangent shall be inserted in the curb line at the corner at right angles to the line bisecting the said interior angle, and at a distance from the building line corner equivalent to the width of the wider sidewalk of the intersecting streets, the said distance being measured along the bisecting line, the curve to connect this tangent with the curb lines otherwise provided for shall have a radius of 6 feet.

As previously stated the use of curves on a park system of roads is extremely desirable from the æsthetic standpoint. For instance a winding road, following the natural contours of the ground along some lake shore or river bank, tends to emphasize

the natural beauties of the surrounding scenery and is much more appropriate than one laid out on more formal lines.

Cross-Sections of Roads and Streets. The general form of the cross-section adopted for a street or a road will depend upon its location and the material with which the surface is constructed.

Several typical cross-sections adopted by some of the leading State Highway Departments are shown in Figs. 26, 27 and 28.

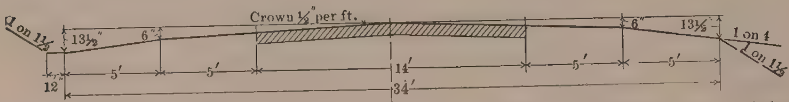


Fig. 26. Standard Road Section. New York State Department of Highways.

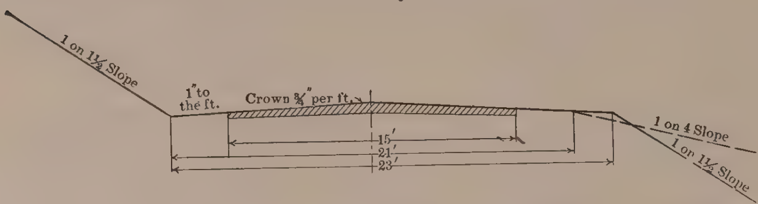


Fig. 27. Standard Road Section. Massachusetts Highway Commission.

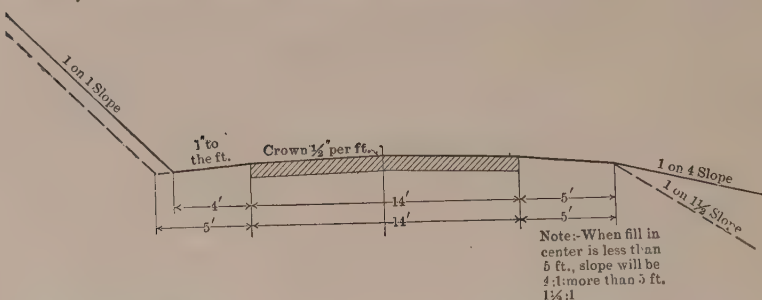


Fig. 28. Standard Road Section. Maryland Highway Commission

The slope of the banks depends upon the kind of material of which they are composed, ordinary earth in a dry state having an angle of repose of 1 on 1½. Some materials, however, will have a much flatter angle of repose. On the other hand solid rock will stand on practically a vertical face. It is customary also in many states to carry out the shoulders of fills, less than

4 feet in height, with a 1 on 4 slope which does away with the use of a guard rail which otherwise would be necessary.

Crowns. The crown for the surface of the carriageway is made up in one of two ways, by intersecting planes or by arcs of a circular or parabolic curve. The purpose of a crown is to give such a shape to the road that it will readily shed the water falling on it to the sides, but it must not be so great as to cause inconvenience or be dangerous to traffic. A steep crown will cause traffic to concentrate on the center of the carriageway with the result that the surface will not be subjected to an even wear. It is a general rule that the smoother the surface the less the requisite amount of crown. For surfaces which are not impervious, such as earth and gravel roads, it has been customary to make the crown on steep grades sharper than on the flat grades for the purpose of shedding the water to the sides more quickly and to prevent it from running down the center of the road. If a heavy crown is used on a road which lies on a steep grade and has a smooth surface, it will be dangerous for the traffic under certain climatic conditions. A well built earth road is generally constructed with a crown of about 1 inch to the foot. The crown used on gravel roads is about ¾ of an inch to the foot. Both earth and gravel surfaces are frequently built with a circular cross-section. The crown of ordinary macadam roads used on state and park systems is usually formed by two planes which intersect at the center of the road and slope away to either side at a rate of ¾ or ½ inch to the foot. Bituminous pavements, when constructed on these classes of roads, do not require so much crown and the slopes now recommended are ¼ to ½ inch to the foot.

Crown Formulas. Crown formulas have been a subject of discussion for many years and throughout the different cities and States in the United States the practice is not at all uniform. These formulas are of two general types. While the derivation of many of them is based on a parabolic curve, some give the total amount of crown, but not its distribution, whereas in others the amount of crown is assumed and the formula gives its distribution. Again some of the formulas do not take the grade

of the road into account, and generally neither do they make any allowance for the different kinds of surfaces with which the pavements may be constructed. Following are given some of the crown formulas which have been used quite generally in different parts of the country in connection with the construction of city pavements.

The following formula, according to T. J. Powell,* Assoc. M. Am. Soc. C. E., was deduced by Joseph W. Dare:

$$C = \frac{W(100 - 4P)}{6300 + 50P^2}$$

C = crown in inches; P = longitudinal grade expressed as a percentage; W = width of roadway in inches.

The distribution of the above crown, when curbs are level, is obtained by the formula $\frac{8C}{0.3R} = d$, where d = the transverse grade, expressed as a percentage, R = width of roadway in feet. In Fig. 29,

$$a \text{ or } b + \frac{C}{18} = \text{the elevation at } A \text{ or } D.$$

$$a \text{ or } b + \frac{C}{12} = \text{the elevation at } B.$$

a and b = the elevation at the gutters, expressed in feet and hundredths. In Fig. 29 it is shown that the transverse slope

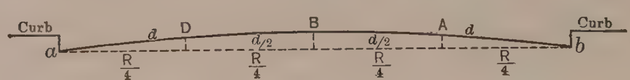


FIG. 29.

between the crown and quarter point is just one-half what it is between the quarter point and gutter.

The crown where the curbs are at different elevations is given by the following formulas and Fig. 30. The letters have the same significance as above.

* See Trans. Am. Soc. C. E., vol. 73, page 225.

$$\frac{a-b}{1.5\,d} + \frac{R}{2} = X.$$

$$b + \frac{Xd}{2} = \text{the elevation at } A.$$

$$b + \frac{3\,Xd}{4} = \text{the elevation at } B.$$

$$a + \frac{3\,Yd}{4} = \text{the elevation at } B.$$

$$a + \frac{Yd}{2} = \text{the elevation at } D.$$

X = the long side of the crown.
Y = the short side of the crown.

This method of computing the crowns of streets has been in use in Washington, D. C., since 1894, and is applicable for all widths up to 50 feet. The crowns obtained are for a sheet asphalt pavement. For pavements having a rougher surface,

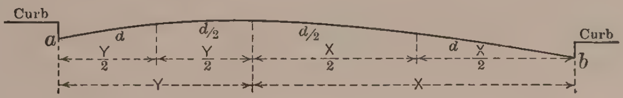


FIG. 30.

such as block pavements, Mr. Powell says the formulas can be used with good results by simply adding 1 inch to the crown obtained by the formula.

Formulas devised in 1902 by Andrew Rosewater are as follows:

For brick, stone block, wood block, and compressed European rock asphalt, $C = \dfrac{W\,(100 - 4\,f)}{6000}$

For American sheet asphalt, $C = \dfrac{W\,(100 - 4\,f)}{5000}$

C = crown of pavement in feet,
W = distance between curbs in feet,
f = grade of street in feet per 100.

It will be noticed that this formula gives the total amount of crown, but nothing relative to its distribution. The total amount of crown being known, however, the elevations at any other points throughout the width of the street can be found by assuming the curve to be a parabola and figuring the ordinates to the curve. The ordinates will decrease as the squares of the distances out from the center.

The following rules were given by George C. Warren* in a paper presented before the American Society of Municipal Improvements in 1909. As will be seen, the rules take into account the grade, width, and kind of surface with which the pavement is built:

"For pavements having smooth surfaces such as asphalt, creosoted blocks, and grouted stone blocks and brick, and having a grade of 2 percent or less, with no car tracks, make the crown 1 inch to each 6 feet of width between curbs.

"For pavements providing more secure foothold, such as stone blocks and brick, having bitumen filled joints, macadam or bitulithic on streets having a 2 percent or less grade, make the crown 1 inch to each 4 feet of width.

"If the street has car tracks, deduct the total width outside to outside of rails from the width between curbs and divide the difference (double width between track and curb) by 6 and 4 respectively.

"For grades between 2 percent and 4 percent, provide one-half the crown provided by the above computation.

"For grades above 4 percent, provide a crown one-third that of the above computation."

To find elevations for quarter points and points midway between the crown and the quarter point and the quarter point and the curb the following rule, suggested by G. B. Zakniser and endorsed by Mr. Warren, is used in connection with the above rules:

"Drop one-eighth the crown at the crown mid-quarter point; drop one-third the crown at the quarter point; drop five-eighths

* See Engineering-Contracting, Nov. 10, 1909.

the crown at the curb mid-quarter point." By quarter point is meant the point midway between the center of the carriage-way and the curb or, in the case of streets on which car tracks are placed, it is the point midway between the outside rail and curb.

Drainage and Foundations. The results of the preliminary examination will furnish much valuable information relative to surface and subdrainage and the foundation. A consideration of these subjects, however, will be given in full in their respective chapters.

Selection of Type of Surface. There are many essential points relative to the materials used and the methods of construction employed that influence the selection of the type of surface, and for this reason it will not be considered further in this chapter, although it is an important part of the design.

Estimates. When the grade of the road and the form of cross-section have been adopted an estimate can be made of the amount of work to be done.

A template corresponding to the form of cross-section should be cut out of some stiff cardboard or a piece of celluloid, the scale used being the same as the scale with which the cross-sections have been plotted. The templates are cut on lines showing the surface of the subgrade. The elevations of points on the subgrade for each 50- or 100-foot station on the center line

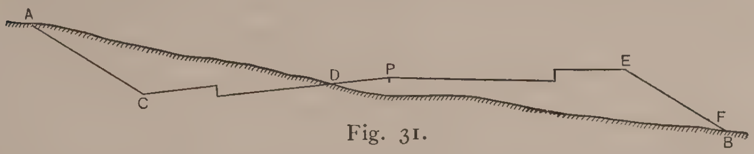


Fig. 31.

of the road or street are computed and plotted on the cross-sections of the original surface at stations to which they correspond.

In Fig. 31 the ground line of the original surface is shown by the line *A B*. The line *A C D E F*, drawn by means of the template, represents the cross-section of the subgrade and sides of the proposed road. The point *P* corresponds to the elevation of the subgrade. It is seen that the area *A C D* is in cut and the

area $D\,E\,F$ in fill. These areas may be determined by means of a planimeter, by counting the squares included between the lines or by dividing the areas into approximate geometrical figures and computing the same. The method to be adopted will depend upon the form of cross-section or profile paper, the scale used, and the personal equation.

The areas at each 50- or 100-foot station and at those odd stations which mark abrupt changes in the slope of the earth's surface are determined. The yardage is computed by the average end area formula. Let A_1 and A_2 be the areas in square feet of cut or fill at any two adjacent stations, a distance L feet apart. The volume in cubic yards of cut or fill for this length will then be

$$\frac{A_1 + A_2}{27 \times 2} \times L.$$

If the station interval is uniform the yardage for any desired length can be found as follows: Let A_1, A_2, A_3, etc. . . . A_n be the areas in cut or fill at the different stations at a uniform interval apart, the total length between the stations A_1 and A_n being L. n equals the number of stations chosen. If the areas are in square feet and L is in feet, the volume for this length will be

$$\frac{A_1 + 2\,(A_2 + A_3 + \text{etc.} \;.\;.\;.\;.\;.\; A_{n-1}) + A_n}{\{\,2 + 2\,(n - 2)\,\}\,27}\,L.$$

It is not necessary to estimate the areas closer than the nearest square foot. Except in very heavy work the actual stations defining the line of intersection of the proposed roadbed and the original ground surface, or in other words the true zero of the cuts and fills, need not be found. The station without any area in cut just immediately preceding a station that has such an area may be considered to be the beginning of the cut; the beginning of a fill would be the station preceding one which has no area in fill; in a similar manner the ends of the cuts and fills would be a station immediately following. If the cross-sections are estimated for each 50-foot station, the above method does not involve much error, and the error that does exist makes the quantities larger.

The following table, which gives the volume in cubic yards contained on a 100-foot length for areas varying from 1 to 30 square feet, will be found to be of great assistance in making estimates. The yardage for any section can be found as follows: Find the mean area of the section to the nearest hundredth; from the table find the volume corresponding to the mean area. It may not be possible to do this directly, but by adding quantities corresponding to various areas whose sum equals the mean area and by moving the decimal point to the right or left, the yardage for any area whatsoever can be found very rapidly. Multiplying the volume corresponding to the area by the length of the section divided by 100 gives the total volume of the section.

TABLE No. 1

CUBIC YARDS OF EXCAVATION OR EMBANKMENT FOR AVERAGE END AREAS VARYING FROM 1 TO 30 SQUARE FEET AND A LENGTH OF 100 FEET.

Area	Volume	Area	Volume	Area	Volume
1	3.70	11	40.74	21	77.78
2	7.41	12	44.44	22	81.48
3	11.11	13	48.15	23	85.18
4	14.81	14	51.85	24	88.89
5	18.52	15	55.55	25	92.59
6	22.22	16	59.26	26	96.29
7	25.93	17	62.96	27	100.00
8	29.63	18	66.67	28	103.70
9	33.33	19	70.37	29	107.41
10	37.04	20	74.07	30	111.11

The following example illustrates the use of the table: Assume that the average area of the sections for a length of 500 feet is 23.46 square feet. To find the volume proceed as follows:

	Area	Volume on 100 ft. Length
	23	85.18
	.4	1.481
	.06	.222
	23.46	86.883
		5
Volume on 500 ft.		434.415 cu. yds.

When specifications contain an overhaul clause, it will be necessary in some cases to make a mass diagram in order to find the places at which it is economical to borrow material. Usually,

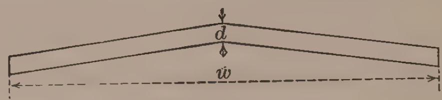


FIG. 32.

however, the cuts and fills are so related that a study of the estimate alone will be sufficient to determine this detail.

The quantity of material contained in the surface may be computed as follows: Fig. 32 shows a surface of uniform depth formed by intersecting planes.

Let d = depth in feet and w = width in feet.

The volume for a length of L feet will be $\frac{w\,d}{27}L$.

If d is not uniform and the depths at the center and sides are d, d_1, d_2, respectively, the average depth is $\frac{d_1 + 2\,d + d_2}{4}$.

Multiplying the average depth by $\frac{w\,l}{27}$ will give the volume.

Fig. 33 shows a surface composed of curves, either circular or parabolic. In this case the area required is that bounded by the two curves. This area may be found by adding the areas of the segment $a\,c\,b$ and the rectangle $a\,b\,f\,e$ and subtracting from this sum the area of the segment $e\,d\,f$. If the curves are

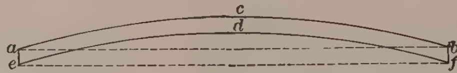


FIG. 33.

circular or parabolic in form these areas can be found without difficulty. As above, the area times the length will give the volume.

A complete estimate, besides the amount of grading and surfacing, will contain quantities of all the work to be done, such as linear feet of guard rail, drain pipe and culvert pipe of various sizes, concrete, ledge excavation, curbing, catch basins, etc.

CHAPTER V

DRAINAGE

Object of Drainage. In the construction of any type of road or pavement, drainage is of the utmost importance. Water is one of the most destructive agents encountered in the construction and maintenance of highways. Provisions for drainage should be made so that water will not stand on the surface or at the sides of the roadway. Another object of drainage is to remove from the subsoil the water which, under certain conditions, has a tendency to rise to the surface. Since the loads which come on a road surface must ultimately be borne by the natural soil, it is obvious that a dry condition of the subsoil is a prerequisite for the proper accomplishment of this duty, since a soil which is saturated with water will have practically no supporting power whatsoever. Drainage may be properly considered under two main heads, namely, subdrainage and surface drainage.

Subdrainage

Conditions Encountered. The kind of soil, the location of the road, and the climatic conditions are factors which influence the necessity for subdrainage. If the subsoil of a road is of a sandy or gravelly nature and the road is located on high ground so that the water as it seeps through the soil readily runs off, subdrainage is not necessary. On the other hand, a clayey or any other plastic soil which readily retains water will, in some locations, become almost impassable unless properly subdrained. Through low places where the water ponds at the side of the road, keeping the subsoil constantly saturated, subdrains will affect a marked improvement. Oftentimes springs will occur on hillsides which, unless led from the road by subdrains, will

soften the subsoil with a consequent failure of the surface at these points. A stratum of rock may lie near the surface and water will collect in its depressions and tend to soften the overlying road. Deep clay soils, and particularly those of stiff clays which do not contain any considerable proportion of coarse sand, should have the water removed from them as much as possible and be kept in a dry state. Certain types of loams are practically as bad as clays when wet. Quicksands have absolutely no supporting power, but if properly underdrained they may serve as a suitable foundation. If water is allowed to remain in the subsoil in cold weather, the ground freezes and expands, thus loosening the soil. In the spring the ice melts, the soil becomes softened by the water and is churned up by the traffic until the road surface is ruined. There are conditions where frost may prove to be harmless, as is shown in the semi-arid regions west of the Mississippi River. There is practically no water in the ground in this locality during the winter when it is frozen, and consequently there is no expansion by the freezing of water in the soil. For this reason there is no heaving or disturbance of the ground.

It is quite essential when the frost comes out of the ground in the spring to provide means so that the water below the surface which has accumulated by the thawing will be immediately carried away. Since the thawing action takes place below as well as near the surface, if the resultant water is not removed the foundation will soon soften. Subdrains properly placed will remove this water. The hydrostatic pressure of water in places higher than the level of the highway may force the water slowly up through the soil, which fact may explain the presence of water in a road during a thaw where it was known that the ground when frozen was perfectly dry.

There are a variety of ways by which subdrainage can be accomplished.

Pipe Drains. One of the best and cheapest methods of accomplishing subdrainage is by means of lines of tile pipe.

The Pipe. The pipe may be made of either cement or vitrified clay. The cement pipes are generally made with plain

ends and the vitrified pipes with bell and spigot ends. The pipes are made in 1-foot lengths for the smaller diameters and in 2-foot lengths for the larger diameters. The pipe for drains should be of good quality, of uniform diameter, with no blisters or bubbles on the inner surface. The pipe should also be free from fire cracks as well as cracks caused by transportation or handling. All clay pipe must be thoroughly vitrified. Glazing, however, is not absolutely essential.

Concrete pipe for drains should be made of the best quality American Portland cement and clean sand and fine gravel in proportions of not less than one part cement and four parts sand and gravel. The gravel used should contain no pebbles whose diameter exceeds ¾ of an inch. The concrete must be mixed wet and thoroughly rammed into the molds before setting begins. The pipe should be allowed to season for at least three months in a temperature above 40 degrees Fahrenheit before being used.

Cost of Pipe. The cost of drain pipe varies with the size of pipe, point of delivery, and the amount purchased.

Diameter of Pipe	Vitrified Clay	Porous Clay Tile	Cement Tile
5 in.	$0.072	$0.03	$0.025
6 in.	0.072	0.035	0.035
8 in.	0.099	0.06	0.05
10 in.	0.144	0.09	0.075
12 in.	0.180	0.12	0.10

These are average prices f. o. b. factory in carload lots.

Determination of Size of Pipe. The requisite size of pipe required depends upon the amount of water to be carried and the grade to which the pipe is laid. There are several formulas by means of which the size can be determined. The assumptions that must be made, however, in applying a formula to any particular case are such as to render an accurate determination of the proper size impossible. For instance, the amount of water to be carried off cannot be more than roughly approximated, and very little reliable data relative to the flow of water in pipes of this kind is obtainable. The amount of water is

generally assumed to vary between ¼ inch and 1 inch per acre per twenty-four hours on the area to be drained, an average value being ½ inch. Experience as to what a tile drain has accomplished in any particular locality is a better guide than any result that may be obtained by formula. It has been well established in practice that the minimum size should be 4 or 5 inches.

In places where no drains have been laid the size of pipe obtained by formulas may serve as a guide to judging the proper size to be used. The following formula is given by Professor I. O. Baker, M. Am. Soc. C. E.:

$$A = 1.9\sqrt{\frac{f\,d^5}{L}}$$

in which A is the number of acres for which a tile having a diameter of d inches and a fall of f feet in a length of L feet will remove 1 inch in depth of water in twenty-four hours. The Poncelot formula, which has been used to a large extent, is

$$v = 48\sqrt{\frac{d\,f}{L + 54\,d}}$$

in which d is the diameter of the tile in feet, f the total fall of line in feet, L the length of line in feet, and v the velocity in feet per second. Kutter's formula, using as a value for "n" the decimal 0.014, gives results which are thought to be more accurate than the Poncelot formula where the drains are properly constructed. The following table by Spalding gives the capacity of tile drains in cubic feet per minute:

Slope per 100 feet in inches	SIZE OF PIPE				
	4 inch	6 inch	8 inch	10 inch	12 inch
2	4.0	12.0	27.0	49.5	81
4	5.5	16.5	38.0	70.0	114
6	6.5	21.0	46.5	86.5	143
9	8.0	25.5	57.5	106.5	176
12	9.5	29.5	66.0	122.5	204
24	13.5	41.5	92.5	173.0	288
36	16.5	51.0	114.0	212.0	353
48	19.0	59.0	132.0	245.0	408
60	21.0	66.0	148.0	275.0	456

Laying the Pipe. The pipe is usually laid at the sides of the road along the lines of the open ditches and at a depth of 2½ to 3 feet below the bottom of the ditch. On hills the pipe may be laid under the shoulders of the road, since, if placed in the ditch, it is liable to be washed out. On city streets that are paved and curbed the pipe is frequently laid underneath the curbs. When one line is used it is sometimes located underneath the center of the roadway. This location is not as satisfactory as that at the side, since to repair the pipe will mean disturbing the roadway, as the drain in this position tends to concentrate the water underneath the center of the road. The trench is started at the outlet end, the bottom of the trench being brought to the proper grade. The trench is made 15 inches wide at the top and 12 inches wide at the bottom for 5-inch tile. It is sometimes specified that the bottom of the trench shall be formed with a proper tool so as to fit the pipe, and again that the bottom of the trench shall be covered with a layer of fine gravel or coarse sand in which the pipes may be bedded. The trench should not be dug faster than the pipes are laid. The pipes are carefully laid in the trench, and if provided with a bell end, the bell is always placed at the high end of the pipe. Whether the pipe is of porous tile or of vitrified clay most of the water seeps in through the joints. The joints of pipes with plain ends are protected by wrapping them with a piece of tar paper or burlap; the joints of pipes with bell ends may be protected in a similar manner or may be loosely packed with oakum or filled with cement. After the pipe is laid the trench is filled with broken stone, gravel, earth, brush or a combination of these materials.

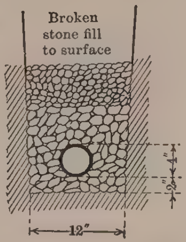


FIG. 34. Pipe Drain.

All drains must be carried to a proper outlet either to a culvert, to another drain, or through the bank. When the drain is carried through the bank the outlet end should be protected by a masonry or concrete wall which extends back along the

pipe for a distance of 2 or 3 feet, thus preventing the water from undermining the pipe at this point.

The minimum grade of pipe is specified by some engineers as 6 inches in 100 feet, whereas others will allow as small a fall as ½ inch in 100 feet. It should be remembered that the steeper the grade, the greater the capacity of the pipe. The maximum grade may be made any amount.

If the pipe is laid in sand or quicksand, it may be necessary to surround it with sawdust, cinders or some such material to keep out the silt. Locomotive cinders have been found to be an excellent material with which to surround the pipe when the latter is located in a plastic clay which may get into the pipe and clog it. If the material is unstable and there is danger of the pipe settling, boards should be laid in the bottom of the trench before placing the pipe.

In clay soils a tile drain will drain a width about six times its depth on each side; in porous soils the distance drained on either side may be as much as fifteen or twenty times its depth.

One Versus Two Lines. The necessity for a line of pipe at either side of the road is wholly a matter of judgment. Frequently one line may serve as well as two, but there may be occasions where two lines are necessary. In doubtful cases one line can be put in, and if later it is not found to be sufficient, the line at the other side of the road can be built. Generally on side hills where a subdrain is needed, a single line on the uphill side of the road will serve to cut off the water coming through the soil.

Transverse Drains. Another method of constructing pipe drains is to lay lines of pipe at intervals either transverse to the road or in the form of a V, the ends of the pipes opening into the side ditches. The distance between the lines of pipe will vary depending upon the soil conditions and the amount of water that must be carried away. Although some engineers believe this method to be much more effective than that of laying the drains parallel with the center line of the road, nevertheless the latter method is the one most commonly used.

Specifications. The drains, as constructed by the Massa-

chusetts and Maryland Highway Commissions, are laid on 2 inches of broken stone or gravel which will pass through a 1¼-inch mesh and not through a ½-inch mesh; the size of pipe specified is 4-inch salt glazed vitrified clay pipe, with bell and spigot joint; the joints are left open; clean gravel or broken stone of the sizes already described are to be filled about the pipe and over it for a depth of 1 foot; the remainder of the trench is to be filled with stone which will pass through a 3-inch and not through a 1-inch screen.

Cost of Pipe Drains. Pipe drains are generally paid for at a price per linear foot, the cost of trenching, refilling with gravel or broken stone, the cost of pipe and laying all being included. In 1910 an average price per foot for pipe drains in state road work in New Hampshire was 50 cents. The average contract price for pipe drains on roads built in 1910 by the Maryland State Highway Commission was about 45 cents per linear foot.

Blind and Other Drains. Blind drains, so-called, are generally constructed by excavating a trench from 1 to 2 feet in width and of a depth depending upon conditions encountered,

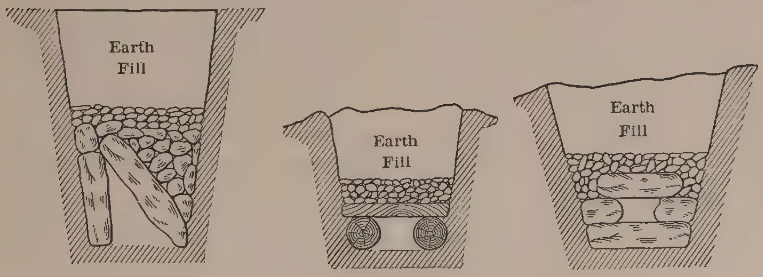


Fig. 35. Types of Stone and Log Drains.

the trench being filled for the greater part of its depth with broken stone, gravel, or other porous material. Such drains may be constructed alongside or across the road at intervals, and serve the same purpose as a tile pipe, but they are not as effective as pipe drains, since they are more liable to clog up. One place where this type of drain can be used to advantage is to drain the water which may pond in a car track that lies adjacent to the

roadway surface. The stone drains are constructed for the full width of the track between the ties and lead the water away to the ditch.

Several forms of drains constructed with logs and field stones are shown in Fig. 35. These types of drains are liable to clog up, particularly if the stones become misplaced.

The drainage of some soils can be improved by excavating and refilling with a porous material which will drain well. Generally, however, the depth at which the road must be subdrained is such that to accomplish the same by this method would make the cost too great.

Surface Drainage

Side Ditches and Gutters. The crown of the road or pavement serves to remove the water from the surface to the ditches or gutters at the side, whence it follows the longitudinal grade to the point of outlet which may be a culvert, natural waterway, or catch-basin. The amount of crown of different types of surfaces, methods of obtaining same and the minimum longitudinal grade have been previously discussed in Chapter IV.

It is usually only necessary to construct ditches in the cuts, since on fills the grade of the road is raised above the general ground level and the shoulder of the fill holds the water back. When the fills are shallow or the road has a steep grade, however, the construction of side ditches may be advisable to protect the shoulder of the road. The ditch or gutter usually has the same grade as that of the center of the road, although on very flat grades the ditch may have a steeper grade than this. The cross-section of the ditch is made in a variety of ways depending principally upon the tools or machines with which the construction of the ditch is accomplished. There are three principal forms, V-shaped, the trapezoidal cross-section, and the wide flat ditch, which is really a continuation of the slope of the road surface, but at an increased rate. Unfortunately the side ditches are frequently constructed so that they are inadequate to take the water, unsightly in appearance, and dangerous to the traffic. A ditch having a trapezoidal or a V-shaped cross-section will

carry more water, but is very much more liable to gully out than one constructed wide and flat. Another advantage of the wide and flat ditch is that it is not so dangerous for the traffic and it is much easier to construct and maintain, particularly if a road grader is used in accomplishing the work. The width and depth of the ditch depend upon the amount of water to be carried, and vary to some extent with the width of the road; the slope on

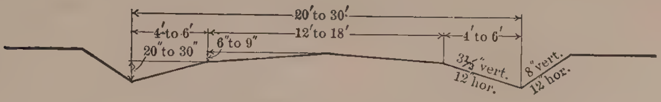


FIG. 36. V-shaped Ditch.

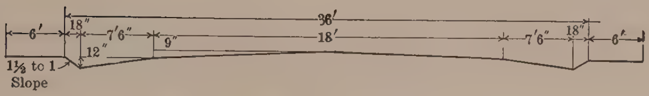


FIG. 37. Wide and Flat Ditch.

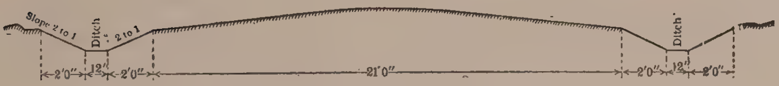


FIG. 38. Ditch with Trapezoidal Section.

the side adjacent to the travelled way may be made about 3 to 4 inches per foot, while the slope from the bottom to the far side is about 8 inches to the foot. Typical sections of ditches are shown in Figs. 36, 37 and 38.

Water should not be carried too great a length in a ditch before it is given an outlet, since the amount of water will become so great that the capacity of the ditch will be exceeded and gullying will result. It is also easier to turn off a small amount of water into the adjacent fields, without objection on the part of the property owner, than it is to dispose of a large amount in this manner. On hills where the grade exceeds 3 percent and the soil is loose and sandy, it may be necessary to pave the ditch with cobble-stone, field stone, brick or paving blocks in order to prevent gullying.

The construction of gutters used in connection with the various city pavements is considered in detail in Chapter XXV.

There are places along the road where the water may be turned off at either side, such places, for instance, as a fill with the ground sloping away from the road on both sides. If there is much water to be turned over a bank in this manner it will be necessary to protect the bank from washing out. A small amount of water running down high banks composed of sandy soil is liable to cause great damage, for the small gullies made by the

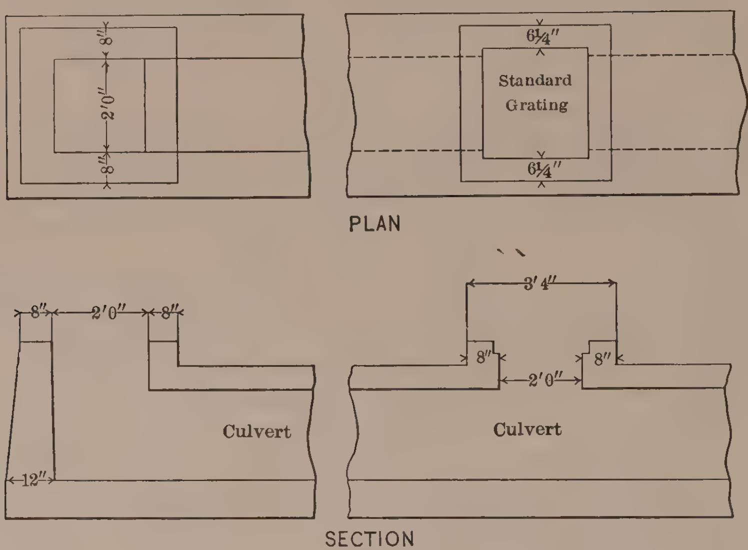


FIG. 39. Concrete Box Inlet. New York State Highway Department.

water may rapidly extend back into the road surface. The bank should be protected by sod, or a paved gutter, the stones of which are cemented together, should be built down the side of the bank to carry the water. In soils where there might be some question as to the advisability of using a gutter, a vitrified pipe or a wooden trough may be built down the side of the bank.

Culverts. Culverts are placed at the low points and at other points where it is desired to take the water from one side of the road to the other. The determination of the size, the

construction and cost of culverts of different types are treated in Chapter XXVI.

Drop Inlets. The contour of the ground will be such that frequently the inlet end of a culvert will have to be placed some distance below the bottom of the ditches leading to it. Where this distance is not too great, it is possible, at such points, to construct a drop inlet which is nothing more than an open box of concrete or stone masonry which keeps the earth away from the end of the pipe, as shown by Figs. 39 and 40. In case the inlet is far enough removed from the travelled way so as not to be dangerous to the traffic, no grating is necessary over the top.

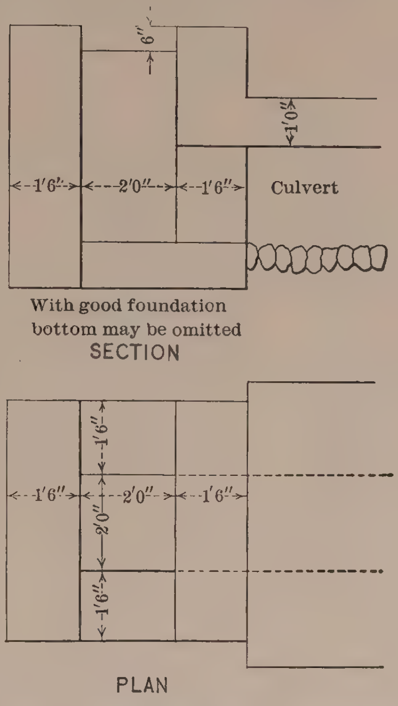


FIG. 40. Stone Box Inlet. Maine Highway Department.

Catch-Basins. In places where the wash carried along by the water is of large amount, the construction of a catch-basin is more advisable than a drop inlet, since there is not so much danger of the pipe becoming choked. The size of the catch-basin will depend on just how much material is liable to be washed into it and how often it is to be cleaned out. The inlet should offer as little obstruction as possible to the water, and the grating should be of such a form as not to be dangerous to traffic. The outlet pipes of catch-basins in cities frequently connect with sewers carrying house sewage, and it is essential in such cases that the pipes be trapped in order to prevent the emanation of objectionable gases from the sewers. A simple method of preventing floating débris from entering the sewer is

to place an elbow, turned down, at the end of the outlet pipe. If the soil drains well it is not absolutely necessary to build a bottom to the catch-basin, but the danger that exists in undermining the side walls when cleaning the catch-basins makes it advisable to always construct a bottom.

Figs. 41, 42 and 43 show catch-basins that are typical of

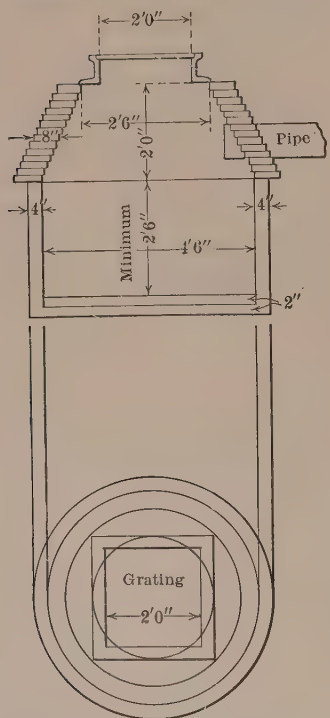


FIG. 41. Brick Catch-Basin. Rhode Island State Board of Public Roads.

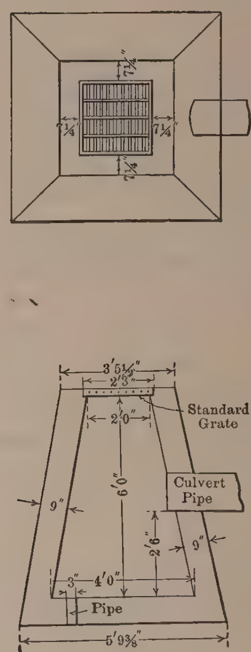


FIG. 42. Concrete Catch-Basin. New York State Highway Department.

those used in connection with the construction of state highways. Those built of brick are generally of circular cross-section, while those built of concrete are square. The average approximate cost of catch-basins of this type constructed in place, including the cost of excavation, grating, and all other materials, will vary between $30 and $40.

Figs. 44 and 45 show two types of catch-basins that are the tandard forms used in the Borough of the Bronx, New York City. It will be noticed that in Fig. 44 a granite head is used nd in Fig. 45 a cast-iron head is employed. The only inlet or water in the former is the vertical opening furnished by neans of the granite head. The cast-iron head, however, pro-

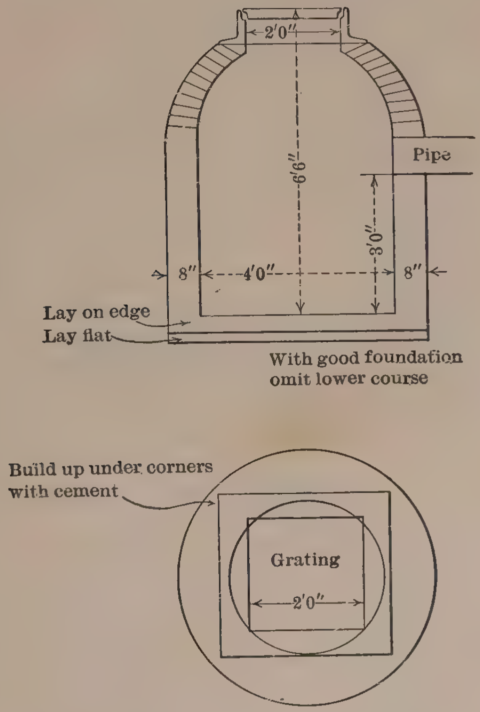


FIG. 43. Brick Catch-Basin. Massachusetts State Highway Commission.

vides both a vertical and horizontal opening. The catch-basin as illustrated by Fig. 44 is cleaned through the manhole that ies in the plane of the sidewalk, while in Fig. 45 access to the basin is had by means of the grating located in the gutter. A detail which is of importance, where the catch-basin is connected to the sewer, is the 4-inch clean-out pipe shown in both Figs. 44 and 45. By means of this pipe it is possible to flush out

any sediment that may have gathered in the pipe connecting the basin and the sewer.

Inlet Castings. There are many different types of castings

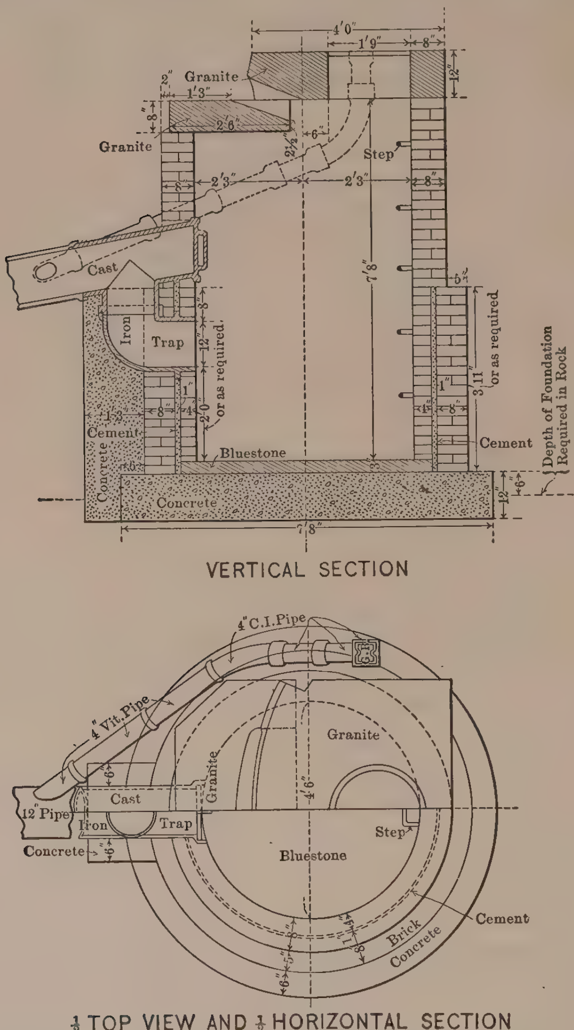


FIG. 44. Brick Catch-Basin. Borough of the Bronx, New York.

which are used as catch-basin covers and inlets. If a casting is so placed that traffic will pass over it, a much stronger type

will be required than when this is not the case. Figs. 46, 47 and 48 show inlets which are used to a considerable extent on park highways and on roads where there are no curbs. Attention

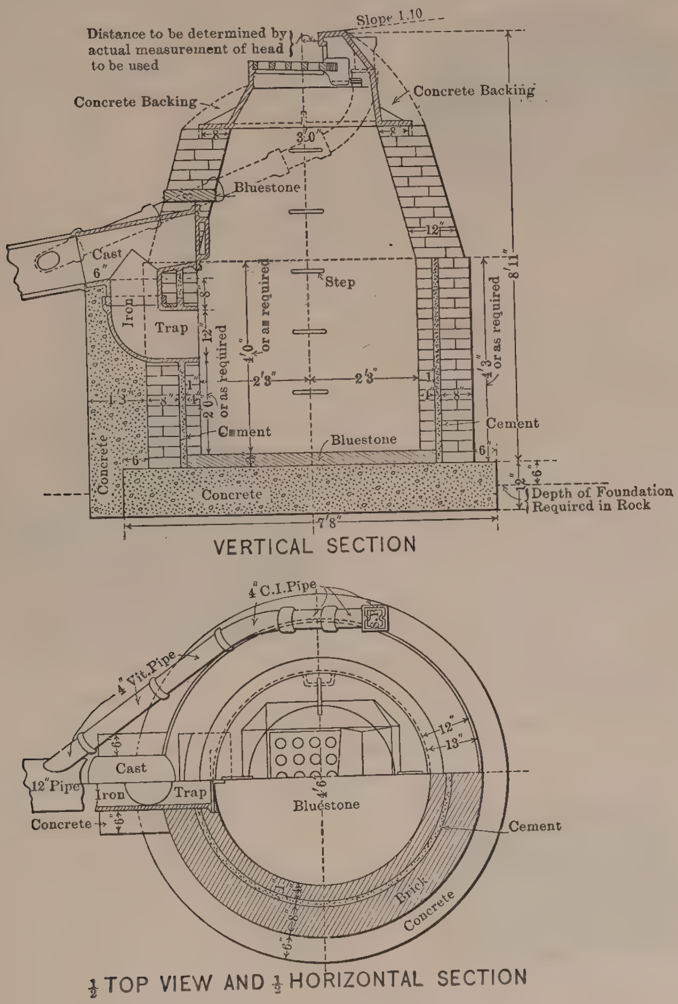


FIG. 45. Brick Catch-Basin. Borough of the Bronx, New York.

is called to the construction as shown by Fig. 47, the casting of which has a raised portion on the back so that if the lower

part becomes clogged the raised part will still take water. Fig. 46 and Fig. 48 show two types of inlets which lay flat and are sufficiently strong to take the traffic. These types are frequently used with great satisfaction in road work, and may be used also within the cities as well, the grating being placed in the gutter next to the curb. Those gratings with longitudinal openings extending the full width of the grate should be placed so that the openings are perpendicular to the line of travel. Covers for catch-basins and manholes should be roughened so that the danger from slipping will be avoided. This is essential whether the catch-basin is located in the sidewalk or the carriageway. Fig. 49 is a view of the iron casting used in the construction of catch-basins in the Borough of the Bronx, New York City.

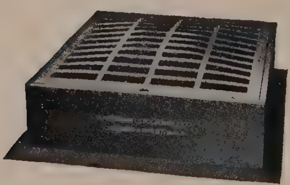
Courtesy of the Barbour Stockwell Co.

FIG. 46. Inlet Casting.

Courtesy of the Barbour Stockwell Co.

FIG. 47. Inlet Casting.

Location of Catch-Basins. Catch-basins on roads are located with the inlet in the gutters or ditches. Since generally no curb exists, the inlet serves as the only opening to the basin unless a special form of casting is used, as shown in Fig. 47. In cities where the water drains towards a street intersection there are two methods of placing the catch-basins. One method is to place a basin or inlet at each corner. Such a procedure, however, does not allow the construction of an efficient inlet, and, moreover, the inlet coming directly at the corner usually causes the



Courtesy of the Barbour Stockwell Co.

FIG. 48. Inlet Casting.

flooding of street crossings during rain storms. In the other method a basin or inlet is located on both sides of the corner. It is not necessary to construct more than one catch-basin in this case, since one may serve for the two inlets. The inlet to the catch-basin is sometimes only a vertical opening in the curb. Again, some form of casting is used which provides a horizontal well as a vertical opening. Frequently catch-basins

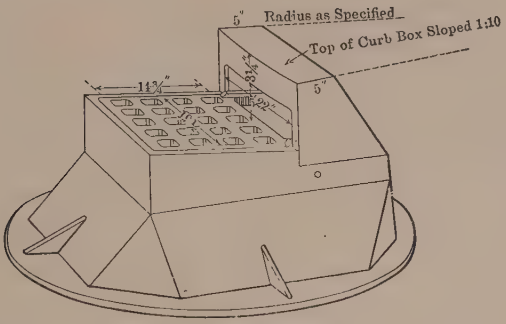


FIG. 49. Inlet Casting. Borough of the Bronx, New York.

are constructed entirely beneath the sidewalk. This method has the objection that in cleaning the basin the sidewalk is obstructed. If the basin is constructed partly under the sidewalk and partly under the gutter with the cover or grate through which the basin is cleaned in the gutter, the above objection is done away with.

CHAPTER VI

FOUNDATIONS

Necessity of Foundations. All loads must ultimately be carried by the subsoil. The subsoil, without the construction of some artificial foundation in addition, will not be sufficient under most conditions. All forms of block pavements and sheet asphalt, for instance, cannot be built and maintained successfully on a subsoil foundation alone. It is practically impossible to make every part of a soil foundation the same, and a rigid uniform base is one of the essentials to success in the construction of any of the above pavements, otherwise the surface soon loses its shape, which accelerates the wear. The importance of thorough drainage of the subsoil should be realized, since no matter what form of foundation is contemplated, a poorly drained subsoil will endanger its success.

The conclusions of the Second International Road Congress held in Brussels in 1910, in regard to foundations, are:

"The strength of road foundations should be increased in proportion as the supporting power of the ground decreases. The foundation should have more body and resistance, the more it is exposed to internal deterioration and external wear.

"In the choice of the system of foundation for both stone block pavements and metalled roads, due consideration should be given to the condition of the subsoils, with regard to the possibility of their drainage, to their geological nature, and to the nature of the materials of the locality. In order to determine the thickness and the extent of the foundations, the pressure per unit area should be made compatible with the carrying resistance of the soils, observed under the most unfavorable conditions."

Classification. The subject of foundations will be considered under two main heads, namely, natural foundations and artificial foundations. With the exception of earth roads, the

construction of all of the more common types of roads and pavements might be described as three distinct steps: the construction of the subgrade or natural foundation, the construction of an artificial foundation, and the construction of the wearing surface. On this assumption, therefore, the lower courses of either a macadam or a gravel road will be considered as types of artificial foundations.

Natural Foundations

The natural foundation must be considered in all cases. It is ordinarily composed of some kind of soil, although there may be instances where a rock subgrade may be encountered. The formation and occurrence of the different kinds of soils will first be discussed.

Soil Classification. Soils are formed by the decomposition of mineral, animal, and vegetable matter. The majority of soils, however, are of mineral origin and are formed by the breaking down of rocks through the agency of the wind, water, and glaciers in combination with the temperature changes, chemical action, and plant growth. Soils may be designated as sedentary or transported: sedentary soils are those which remain near their source of formation, while transported soils, as the name implies, have been carried by some geological agency, generally either rivers or glaciers, from the place where they were first formed to some other. The principal constituents of any soil, whatever its source, are nearly always silica, with varying amounts of alumina, oxides of iron, lime, magnesia, and the alkalies, together generally with a small amount of organic matter. Due to the same agents which disintegrate the rock, the constituents of the soils are constantly changed in character and amount. Some of the more common soils encountered in highway work are classified as gravel, sand, clay, loam, marl, peat and muck.

Gravel. Gravel consists of small pieces of rock worn smooth by abrasive action which would be retained on a 4-mesh sieve. It is generally found mixed with sands and clays in

varying proportions. Most of the gravel in the northern part of the United States is glacial deposit. The district at one time covered by the glacier was all of New England and Canada and that part of the United States north of a line running from a point just south of New York City to the southwest corner of New York State, then closely following the Ohio River to its mouth, the Missouri River as far as Topeka, and thence a little south of the Missouri River and westward to the Pacific coast. This immense ice sheet in its forward movement sheared off the rocks and carried them along in its path. The glacial rivers aided further to break up and distribute the débris picked up by the glacier. With the melting and consequent receding of the glacier, the materials picked up in its path were deposited sometimes to be further distributed by the water from the melting ice. On account of the large variety of rocks passed over by the glacier and the intermingling and mixing of the worn and abraded pieces by the water, it is not surprising that gravels usually present a great range of quality. The larger stones are generally quite hard, since the softer stones have been entirely broken up by the abrasive action.

Throughout New England, the Adirondack district, and the Appalachian belt south to the limit of the ice sheet in that direction, Shaler says, a "blue gravel" abounds, so-called because it is made up largely of trap rock crushed by the glacier, and left near the point where it originally existed, and hence has not been much affected by the action of water. Gravel in which the stones are largely composed of quartz is also extremely common, both in New England and some of the other States to the west. One of the most famous gravel deposits in the East is at Peekskill on the Hudson. Within the Middle States the stone in the gravel deposits for the most part can be traced to an origin from north of the Great Lakes. The Paducah gravel in Kentucky contains, in fact, also material which in part came from north of the lakes. Shaler says, "Over a large part of what is commonly called the Southern Plain, that portion of the South which has in general a little indented surface sloping from heights of about one thousand feet toward the sea, there occurs

a very widespread deposit composed in large measure of rounded pebbles, small boulders, and gravelly bits more or less mingled with clay and sand. This obscurely bed-like surface accumulation has been termed by McGee the Lafayette formation. The origin of the mass is not yet determined, but it is probably made up in part of ancient river gravels and in part of the hard portions of a great thickness of rock which has disappeared by the leaching action of the surface waters. Deposits of this nature are tolerably common over a large part of the non-glaciated district of the United States east of the Cordilleras. The sheet often attains a thickness of some scores of feet, and not infrequently has the aspect of a slightly compacted conglomerate or pudding-stone."

Sand. Sand is largely the result of the decomposition of sandstones and contains no particles which would be held on a 4-mesh sieve. Quartz, which is crystallized silica, is usually found in all sands in greater or less amounts, but the statement that sand is silica is not necessarily true, if the name is to be applied to any crystalline mineral or mixture of minerals which have been broken into small fragments. Sands are generally designated as fine, medium, and coarse. All sands are generally required to be gritty, and it is quite safe to say that the greater part of the sand passing a 200-mesh sieve might lack this property. Quicksand is sand saturated with water and has no stability.

Clay. Clays result chiefly from the decomposition of feldspar, oligoclase, and micaceous rocks. A soil might be termed clay when containing at least 60 percent of this material. When wet a clay becomes very plastic and is extremely unstable and, due to its impermeable qualities, it slowly dries out. When dry a clay becomes extremely hard in quality and contracts to such an extent that the areas where large clay deposits occur are traversed by wide cracks when the clay is in this condition. In the Southwest a clay of which mud bricks might be made is called "adobe."

Shale. Shales are chemically the same composition as clays, but have become hardened. They have a laminated structure and are similar in appearance to slates, but will rapidly disintegrate on exposure to the atmosphere.

Loam. Loams may be any soil between sand and clay, as they contain more or less of each of these two materials. They may be classified as heavy clay loams, clay loams, sandy loams, and light sandy loams, depending upon the quantity of the sand or clay content. Stockbridge classifies loams as follows: "Heavy clay loam with 10 to 25 percent of sand; clay loam with 25 to 40 percent of sand; loam with 40 to 60 percent of sand; sandy loam with 60 to 75 percent of sand; light sandy loam with 75 to 90 percent of sand; while soils with less than 10 percent of loam are either sand or clay, as the case may be." In the Middle West a black loam which contains so much clay as to be sticky when wet is known as "gumbo."

Marl. Marl is a term which applies to all calcareous clays containing as a minimum 15 percent of carbonate of lime and as a maximum 75 percent of clay. The larger the proportion of carbonate of lime, the less plastic is the material until finally it is no longer considered as marl, but is called argillaceous limestone. When partly indurated it is similar to shale or slate, but is readily broken down on exposure to the atmosphere.

Peat and Muck. Peat and muck are generally distinguished from other soils by the presence of humus or vegetable matter. Peat is formed by the decomposition of vegetable matter under water. Humus is the soil resulting from the decomposition of vegetable matter on the surface of the ground.

Methods of Examination. From the highway engineer's standpoint a physical analysis of a soil is of much more importance than a chemical one. It is desirable to know whether a material will make a stable foundation, how it acts in the presence of water, and whether or not it is suitable for filling in embankments. Mention has already been made of the importance of digging test pits at frequent intervals along a proposed road when the preliminary investigations are being made and recording the depths at which the different materials are encountered. If any doubt as to the nature of any particular material exists, samples should be taken of it and further analyzed in the laboratory.

Grading into Sizes. The sizes of the various particles con-

tained in the soil, with the exception of gravel, may be determined by screening the soil through a series of sieves, the smallest sieve used being a 200-mesh and the largest a 4-mesh.

Permeability and Capillary Power. The determination of the permeability of the soil or its ability to allow water to pass through it will be helpful in considering the drainage of any particular soil. Naturally the larger the proportion of fine particles present, the more impermeable the soil. The determination of the power of capillary attraction of a soil may also be of help in considering the proper drainage. It will be found that soils which are the most impermeable generally have the greatest power of capillary attraction; for instance, a sand is the most permeable of soils, but is low in capillary power; clay, on the other hand, possesses just the opposite characteristics. Both of these tests may be made by bringing a soil sample of known volume in contact with a known volume of water, in the case of permeability the water being in contact from above and of capillarity the contact being from below, the time and the depth or height which the water attains in this time being noted.

Loads on the Foundation. The safe loads per square foot specified by Professor William H. Burr, M. Am. Soc. C. E., in structural work on foundations composed of different materials are as follows:

Well-drained clay practically dry..........	8000 to 12000	pounds.
Clay moderately dry......................	4000 to 8000	"
Soft, moist clay..........................	2000 to 4000	"
Coarse sand or gravel in undisturbed and well-bonded strata....................	12000 to 18000	"
Thoroughly compacted and bonded ordinary sand well held in place................	4000 to 8000	"

One of the frequent loads to which a road or pavement may be subjected is a three-horse coal truck which with load will weigh about 10 tons, and approximately two-thirds of this load will be on the two rear wheels. It is generally assumed that the lines of pressure of a load which is supported on an appreciable depth of earth, concrete, stone or other stable material, will diverge

from the point of contact in all directions on an angle of about 45 degrees. If the above wheel had a surface of contact in a longitudinal direction of 1 inch and the tires were 8 inches wide, the area of contact at the surface would be 8 square inches. If the depth of material through which the load is transmitted before reaching the subsoil was 6 inches, the area over which the load would be spread at this depth would be about 260 square inches, according to the above supposition. The pressure on the surface would be about 800 pounds per square inch and 6 inches below the surface, about 25 pounds per square inch. The fact that a wheel usually has a greater longitudinal bearing than 1 inch would tend further to reduce the pressure per square inch.

Theoretically, therefore, the pressure due to a load rapidly decreases through a small depth of material. In practice, however, the above assumptions may be upset by several conditions. A road, for instance, may be slightly heaved up by frost action, the subsoil may be in a moist condition, the tire may not bear on the road for its full width due to the shape of the surface or of the wheel, the load may be transmitted to the surface with a hammering action on account of the roughness of the surface. All of these variables would tend to make the computations as to the pressure and its distribution extremely uncertain and at best they would only serve as a guide to judgment. In any particular locality experience will prove what the supporting power of the foundation is.

Improving the Natural Foundation. The first requisite in preparing any kind of subsoil for a foundation is that it shall be well drained, which, if well done, will tend to eliminate trouble from frost. Gravel, clay, and sand make excellent foundations if this feature is well carried out. A clayey subsoil may be improved by the addition of sand or gravel, while a sandy subsoil may be improved and made more unyielding by the addition of clay well rolled in. Muck, when encountered, should generally be removed for a depth depending upon conditions and replaced with some other material. The availability of materials will usually determine which of the following should

be used for adding to or replacing the present soil: broken stone, stone screenings, gravel, shells, cinders, clinker, brick-bats, slag, marls, or shales. The quality of the material need not be as good as that used on the surface since it will not be subjected to the wear of the traffic. Any subsoil will generally be improved by rolling and such a process will show up weak spots that should be replaced with other material. Major W. W. Crosby,* M. Am. Soc. C. E. says: "On bad soils, it is sometimes difficult to get the surface of the subgrade into first-class shape. For instance, in clays, especially in those which contain considerable mica, the subgrade, during the process of rolling, will flake after becoming partly compacted, these flakes appearing both ahead of, and behind, the roller. This condition, in the case of subgrades in cuts, may be caused by too much rolling, but it frequently occurs on fills which the speaker is absolutely certain were not rolled too much. This flaky condition may be overcome satisfactorily by spreading a layer of sand, cinders, or stone dust, as may be convenient, on top of the subgrade, to a thickness of from 2 to 6 inches, and then compacting this layer with the roller, so as to secure an entirely satisfactory surface on which the macadam can be placed without danger of its being mixed with the subgrade material and thus losing any portion of its effective depth."

Artificial Foundations

Artificial foundations are usually constructed either of large stone, broken stone, hydraulic cement or bituminous concrete. Several types of stone foundations are found, which differ in the size of stones used and the manner of laying same. Other materials similar in nature to stone are used sometimes in its place. Brush and plank have been employed in obtaining foundations through swampy land. Old pavements have frequently been made to serve as foundations for surfaces of some other type. The selection of any particular type would be

* See Proceedings, Am. Soc. C. E., April, 1912, page 562.

governed principally upon considerations of the type of surface to be supported, the traffic to which the surface is subjected, and the natural soil conditions. Most of the artificial foundations constructed with stone aid the drainage to a considerable extent, besides directly improving the bearing power of the soil.

Stone Foundations. In this class are included, besides the methods originally proposed by Telford and Tresaguet, V-drain foundations and foundations composed of crushed stone or other similar material.

Telford Foundation. Telford, in constructing broken stone roads, advocated the use of a large size stone foundation carefully placed by hand. His method followed that previously adopted by Tresaguet, the principal difference between the two methods being that Telford placed his foundation on a flat subgrade and obtained the crown in the foundation by using stones of different depths from the center to the sides, whereas Tresaguet's method of using a subgrade parallel to the finished surface is the one generally followed today, although it is invariably called a Telford foundation.

There is considerable difference of opinion as to the necessity of a foundation of large stone under a macadam road, some believing that it should always be used, while others do not think that the additional expense incurred is warranted. There are conditions, however, in which a Telford foundation will give results that are economical, but its universal use should not be recommended since experience has proved that a macadam road without such a foundation on a well drained and compacted subsoil is fully capable of holding up a considerable traffic. Telford is advisedly used on wet soils where small broken stone would be pushed down into the soft soil.

A Telford foundation is usually constructed on a subgrade, the surface of which is parallel to the finished surface of the road. The stones used vary from 3 to 8 inches in width, 6 to 15 inches in length, and from 6 to 8 inches in depth. The stones are carefully laid on the subgrade with the greatest length across the road, and the widest edge down so as to break joints as much as possible. The projecting edges of the stones above the sur-

face are knocked off with a hammer, and the spaces between the stones are packed and wedged with spalls. The whole surface is then rolled with a heavy roller. It is then ready to receive the upper courses of stone.

TABLE No. 2

SHOWING SIZES OF STONE IN INCHES FOR TELFORD FOUNDATION USED IN VARIOUS STATES.

State	Depth as Set on Edge		Width as Set		Length Set Across Road		Remarks
	Max.	Min.	Max.	Min.	Max.	Min.	
Conn.......	8	8	10	6	18	8	Macadam covering formed in one layer.
Mass.......	6	5	10	4	15	6	Two inches of gravel rolled on subgrade as base
New Jersey.	8	8	4	.	10	.	Alternate end stone, double length.
New York..	8	6	10	4	15	6	Used only on unstable ground as foundation for macadam.

Cost. The cost of Telford foundations in New Jersey varies from 50 cents to about $1.00 per square yard. The thickness of the course and the availability of the material largely affect the cost of this type of foundation. In New Hampshire the average price for Telford in place is about 60 cents per square yard. Foundations of this character, 6 inches in depth, have been constructed for about 33 cents per square yard.

V-Drain Foundation. A V-drain foundation is constructed by excavating the roadway for its full width, from 4 to 8 inches

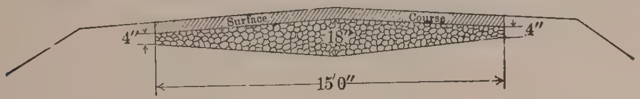


FIG. 50. V-Drain.

deeper at the sides, and from 12 to 18 inches deeper at the center, thus producing a flattened "V"-shaped trench. This excavated space is refilled with boulders and small stone up to the bottom

of the macadam, as is shown in Fig. 50. The larger stones are placed at the bottom of the trench and the smaller stones at the top. The trench is intercepted by culverts, constructed across the road at the low points, which take away the water that flows through the V-drain. A V-drain should only be used where the road lays over wet and heavy soils or on sections of road which break up when the frost comes out.

Cost. The price of V-drain is sometimes stated as so much a linear foot, which is rather indefinite unless the cross-section of drain is known. Contract prices obtained in New Hampshire for this work vary from 75 cents to $1.25 per cubic yard.

Specification. The specifications of the Maryland Highway Commission for V-drain are as follows: "The trench excavated for the V-drain shall be the same width as the macadam, and to a depth of at least 12 inches below subgrade in the center and 6 inches at the sides. The trench shall be cleanly dug true to the lines and grades given. The trench shall then be carefully filled with stone. No stone shall be larger than 8 inches by 6 inches by 4 inches, and none smaller than will pass a 2-inch ring. The largest stone shall be put in the bottom and no point of a stone larger than will pass a 3-inch ring shall be allowed to come within 2 inches of the top surface of the stone in the trench. The stone shall be free from foreign matter, and no earth shall be allowed to fall in the trench after being excavated. After the trench is filled with stone it shall be rolled until firm and solid with a steam roller weighing not less than 10 tons, and any depressions shall be removed by adding more stone. The macadam shall be laid over the V-drain in the usual manner."

Large stone laid flat are sometimes substituted for the Telford and V-drain foundations.

Broken Stone Foundation. The lower course of a macadam road, when the latter is built in two courses, is the foundation for the upper or wearing course. In the United States this course is about 4 inches in depth after compaction for road construction, but should be as much as 6 to 8 inches in order to take the increased loads due to modern traffic. Where the subsoil is poor or the road is subjected to heavy traffic, or it is

desired to aid the subdrainage of the road, the lower course should be increased in thickness or an additional layer of broken stone should be used. This extra layer varies from 3 to 10 inches in thickness and is composed of the larger sized products of the crusher. Gravel, slag, brick-bats, cinders or clinker are often substituted for the broken stone.

Concrete Foundations. Concrete foundations should be used under all types of block pavements, brick pavements, sheet asphalt and other forms of bituminous pavements within the city limits and wherever the traffic conditions are severe. They are constructed in a variety of ways. The thickness of the concrete foundation varies from 4 to 8 inches, 6 inches being an average and usual value. An 8-inch foundation is only necessary when the subsoil is extremely poor or the traffic very heavy. It may be economy in some instances, particularly where the cost of cement is a large item, to obtain the necessary strength for the foundation by increasing the thickness, at the same time using a leaner mixture. Whenever it is necessary to construct a concrete foundation over a trench which has recently been back-filled, the thickness of the foundation, for the full width of the trench and a foot or so on either side, might well be increased to insure against the settlement of the pavement. No matter how carefully the back filling has been placed in a trench, there is always a chance for settlement, and the additional thickness gives the foundation increased strength at this point. Whenever a concrete foundation is constructed, traffic should be kept from it for seven to ten days in order to allow it to set up thoroughly. A concrete foundation, if properly constructed, should outlast whatever surface may be built upon it. Although a concrete foundation is more or less impervious to water and prevents it, to some extent, from rising from the subgrade to the pavement, this fact precludes the necessity for thorough sub-drainage.

The Concrete. Briefly stated, concrete is a mixture of hydraulic cement, sand, and broken stone or gravel. The best and strongest concrete will result when the sand is sufficient in quantity to just fill the voids in the stone, and enough cement

is used to fill the voids in the sand and stone. An accurate proportioning of the materials can only be made by carefully determining the voids of the various ingredients, and since the sand, stone, and gravel are quite variable in this respect, frequent determinations should be made. It is customary in practice, however, to adopt certain proportions as a 1:2:5, a 1:3:6, or a 1:2½:7, the first figure indicating the number of parts of cement, the second figure the parts of sand, and the third, the parts of the large aggregate.

The 1912 specifications of the Association for Standardizing Paving Specifications covering the sizes of the aggregates for concrete foundations to be built by the mixing method are as follows: "The fine aggregate shall consist of any material of siliceous or igneous origin, free from mica in excess of 5 percent, and other impurities, and shall be of graded sizes ranging from ¼ inch down to that which shall be retained on a No. 100 standard sieve, not more than 20 percent of which will pass a No. 50 standard sieve for the base; and from ¼ inch down to that which will be retained on a No. 80 standard sieve not more than 20 percent of which shall pass a No. 50 standard sieve for the top. The coarse aggregate shall be sound gravel, broken stone or slag, having a specific gravity of not less than 2.6. It shall be free from all foreign matter, uniformly graded, and shall range in size from ¼ inch up, the largest particles not to exceed in any dimension one-half the thickness of the concrete in place." Two kinds of cement are used, namely, Portland and natural, there being many brands of each. At one time there was a considerable difference in the prices of these two cements, which is not so marked at present, and natural cements, which were the cheaper, were more commonly used for this kind of work. A natural cement, however, does not produce as strong a concrete and it obtains its initial set much quicker than a Portland cement. On this account, and due to the fact that the two cements are more nearly equal in price, Portland cement is usually specified to be used in all classes of concrete foundations.

Mixing Method. The cost of a concrete foundation con-

structed by the mixing method will vary depending upon the richness of the mix used, the handling of the different materials preliminary and subsequent to the mixing, and upon the method of mixing.

One method of laying a concrete foundation is to mix the ingredients either by hand or machine at a point near where it is to be placed. The proportions having been adopted, the various ingredients are measured out by volume and mixed together with water until the desired consistency is obtained. There is some difference of opinion as to the amount of water to be used, some engineers prefer a dry mix, whereas others use a wet mix. A dry mix requires a great deal more tamping to get the concrete into place and does not make as dense a mixture as a wet one. A mixture which may be easily placed with good results will be obtained if enough water is used so that the resultant concrete is somewhat sloppy, but not so much so that any of the water will run away from it, or so much as will cause a segregation of the ingredients. The concrete thus mixed is placed upon the prepared roadbed to the required thickness. The concrete is then tamped and smoothed with the backs of shovels until the free mortar rises to the surface. Since in the majority of types of pavements a layer of some kind of material is interposed between the surface of the foundation and the wearing surface material, any very slight irregularities in the surface of the foundation will not cause any great trouble. When an absolutely smooth surface is required the surface of the concrete should be struck with a template that will give the desired shape. No concrete should be mixed or laid when the temperature of the air is below 32 degrees Fahrenheit. If it is expected that concrete, which has been laid but has not set, will be subjected to a temperature below 32 degrees Fahrenheit it should be covered to protect it from damage. Remixing concrete which has partially hardened with water should never be permitted. Care should also be taken in conveying the concrete from the place where it is mixed to the place where it is deposited to see that none of the ingredients are lost. When the foundation is completed it should be kept moist for at least two or

three days. When the sun is extremely hot it may also be necessary to cover the concrete during this period.

Hand Mixing. One method of hand mixing is to spread the sand for a batch in a thin layer in the form of a square or a rectangle on the mixing platform. The required amount of cement is then spread out on the sand and the two are turned with shovels in a dry state until thoroughly mixed. Water is then added and mixed with the sand and cement, thus making a mortar. The mortar is spread out in a thin layer in a similar manner to the way the sand was first spread. The required amount of the large aggregate, which has been previously wet down, is then brought to the platform and spread out over this layer of mortar. The mortar and the large aggregate are then turned until thoroughly mixed. In another method the water is not added until the large aggregate is being mixed with the sand and cement.

The mixing platform is made of boards and should furnish a smooth and tight surface to get the best results. The arrangement of the men for turning a batch will depend somewhat upon the number of men in the gang, but the following arrangement when four men are used will serve to illustrate the principle: It will be assumed that the sand and the mortar are always spread in a thin layer previous to turning and that the layer is approximately rectangular or square in shape. One man is placed at each corner of the figure facing each other. They shovel towards each other beginning at the edge and turn the ingredients over away from the center of the figure, taking care to still keep the materials in a layer of about the same thickness as that of the original mass. Each pair of men works towards the center of the mass until they meet. The material thus has all received one turn. The men then start at the center and work towards the outside edge, turning the concrete towards the center, keeping the mass flat as before. When each pair reaches the outside edge the mass has had two complete turns. The men should not be allowed to pile the concrete, as the whole secret of economical hand mixing is in getting the desired result with the least number of turns, and if the men tend to get the

concrete in a pile, the efficacy of the method is seriously impaired. The following table is given by Gillette as representing the cost of mixing and placing concrete by hand under the following conditions: The stock piles are within 60 feet of the mixing board; the specifications call for 6 turns and require that the concrete shall be rammed in 6 inch layers; the gang is composed of 16 men at $1.50 per day and 1 foreman at $2.70 per day; the concrete can be shovelled off of the platform into place.

	Per cu. yd. concrete
Loading sand, stone and cement	$.17
Wheeling 60 feet in barrows (4 + 2 cents)	.06
Mixing concrete, 6 turns at 5 cents	.30
Spreading and ramming	.08
	$.61
Foreman	.07
Total	$.68

A gang of this size under the above conditions will place about 40 cubic yards of concrete in a day, an average of 2½ cubic yards per day per man being a fair day's work.

Machine Mixing. The concrete mixing machines employed in street paving work are generally either some type of batch or continuous mixer. One of the main objections to a continuous mixer is the uncertainty of securing the right proportions of the ingredients. There are several types now on the market, however, that have been used with considerable success under intelligent supervision which have overcome this difficulty to a great extent. In the continuous machines the mixing is generally accomplished by means of paddles fixed to a revolving shaft which mixes the materials together as they fall into the mixing trough and at the same time pushes them towards the discharge end. The machine shown in Fig. 51 has three hoppers, the one in the middle and at the top being for cement, and those on either side being for the sand and stone respectively. Water is added to the mass when it reaches the mixing trough. The amount of work accomplished with some types of continuous

FIG. 51. Continuous Mixer.

mixers compares very favorably with that done with the smaller sizes of batch mixers.

In the case of batch mixers each batch of concrete is mixed separately and the mechanism does not have to be depended upon for the accurate proportioning of the mix. There are several types made similar to that shown in Fig. 52, which are portable and especially designed for street-paving work. The mixing drums of batch mixers vary in shape, the one shown being cylindrical, others are cubical, and still others conical. In all types the drum revolves, turning the concrete over and over. Some machines are equipped with a swinging steel boom and bucket, the latter traveling along the boom from the discharge end of the mixer which does away with wheeling the concrete within an area that can be reached by the boom.

The output of a mixing machine will depend upon the size of the machine, the arrangement of the plant, and the accessibility of materials. Amounts as high as 100 cubic yards and more a day have been laid in foundation work for pavements by both mixers of the batch and the continuous type. In street-pavement work it is customary to distribute the stone and sand in separate windrows along the street. If the windrows can be placed close to the machine and the mixer is backed away from the work as the concrete is deposited, the labor cost of mixing will be materially reduced. When it is impracticable to deposit the materials in windrows along the line of work, stock piles are located at wide intervals. The mixer is set up at these points and the mixed concrete is carried to the work either in wheelbarrows or carts.

The following is a record of actual work accomplished with a No. 2½ Foote Concrete Mixer: The gravel and sand were deposited in windrows along the street and the mixer worked alongside of these windrows and was moved back from the work as it was completed. A total of 18 men were used, the gang being composed of 4 men shovelling gravel into the mixer, 2 shovelling sand, 4 wheeling mixed concrete, 2 spreading concrete, 2 tamping, 2 on mixer, 1 engineer, and 1 foreman. With this force as much as 110 to 128 cubic yards of 6-inch concrete were

FIG. 52. Batch Mixer.

laid in eight hours. Assuming that the cost of labor was $1.75 per eight-hour day, engineer $3.50, and foreman $3.50, the total labor cost of laying 110 cubic yards of concrete would be $35.00 or approximately 32 cents per cubic yard.

The following instance of cost is taken from "Concrete Construction," by Gillette and Hill. The concrete was mixed at a stationary plant in a No. 2½ Smith mixer and a ½ yard cube mixer of the batch types. The mixers were charged from large storage hoppers built directly over them. The mixed concrete was taken from the mixers to the work in patent bottom dump-wagons, the longest haul requiring thirty minutes. Exclusive of overhead charges and with labor at $1.75, teams at $4.00, engineer and fireman at $3.00 each, and engine at $5.00, on the basis of a ten-hour day, the concrete was mixed and placed according to the following costs:

	Per cu. yd.
To mix	$0.12 to $0.15
To deliver to street	0.10 to 0.14
To spread and tamp in place	0.08 to 0.11
Total	$0.30 to $0.40

The contract price of a 1:3:6 concrete foundation, mixed and placed, will be about $5.00 to $7.00 per cubic yard in place, which will make the cost per square yard from about 83 cents to $1.16, if the foundation is 6 inches thick.

In Situ Method. A second method of construction, known as "in situ," consists of spreading and rolling a layer of broken stone of the required thickness in a manner similar to the construction of the bottom course of an ordinary macadam road. A 1:3 mixture of cement and sand in a dry state is spread over the surface and swept in. The surface is flushed with water, rolled, and more dry mortar spread on, during continued flushing and rolling, until all voids are filled.

Cost. The detailed cost of a foundation laid in this manner on one of the sections of the White Plains Experimental Pavements constructed in 1910 in the Borough of The Bronx, New York City, is given below. The length of this section is 150

feet and contains 354 square yards. The foundation was 4¾ to 5 inches thick:

		Per sq. yd.
Labor	$19.96	$0.056
1½-inch trap rock, 59 cu. yds. @ $1.65	97.35	0.275
Screenings, 9.0 cu. yds. @ $1.65	14.85	0.042
Cement, 20¼ barrels @ $1.35	27.34	0.077
354 sq. yds. @ $0.45	$159.50	0.450
Spreading 1½ inch stone		0.054
Total		$0.504

The item for labor includes supervision and rolling.

Grouting Method. In a third method a layer of broken stone is deposited on the subgrade of sufficient depth to make the requisite thickness of concrete. The layer is thoroughly rolled and is then poured with a grout composed of one part cement to four parts sand. The grouting and rolling is continued until the voids in the stone are filled. The Hassam Paving Co., of Worcester, Mass., use special grout-mixing tanks in connection with this kind of work. The grout flows from these tanks through a spout to the point on the road where it is to be used, the grout being continually agitated.

Concrete Slabs. A fourth type of concrete foundation consists in previously molding slabs of concrete of the desired thickness, and laying them on the subgrade in a manner similar to paving blocks. A trial of this kind of foundation was recently made at Vilvorde, Belgium. The slabs used were made of seven parts by volume of granulated slag from blast furnaces, which had been ground and mixed with one part of cement. Two sizes of slabs were used: 16 by 17 by 6 inches and 16 by 16 by 4 inches. This foundation supported a block pavement, a sand cushion 4 inches thick being placed between the blocks and the slabs. The slabs themselves were bedded on a sand layer about 1½ inches thick. Although the resulting pavement did not prove successful, it was not thought to be the fault of the foundation in any way. Some of the advantages of a foundation of this kind are claimed to be as follows: as the slabs have been molded and aged it is not necessary to wait for the concrete to

set up; the foundation may be constructed without handling all of the various materials on the street, which sometimes is a difficult and costly proposition; any repairs necessary to sub-surface structures may be more readily made since the slabs can be removed as a whole and later replaced.

Foundations Over Marshes. Sometimes it becomes necessary to carry a road across marsh land which is extremely unstable, so much so that a crow-bar will sink in it of its own weight. When the topography of the land is such that there is no opportunity for subdrainage, unless a very heavy fill is put in which will be several feet above the level of the marsh, some support will have to be given to the fill. In any event there will be more or less settlement and no improved form of surfacing should be placed on the fill until all settlement has ceased.

Paul D. Sargent,* M. Am. Soc. C. E., describes the construction of a brush mattress under a new fill for improving the bearing power of a bog on two roads as follows: "For this work, boughs of pine, spruce, fir, or hemlock were used, care being taken to exclude those having stems more than 2 inches in diameter. These boughs were laid shingle fashion in courses, first crosswise and then lengthwise of the road, and were four courses deep, that is, two transverse and two longitudinal layers, the total depth being 16 inches. On the boughs was placed a 2-foot fill of gravel. One of these roads was built in 1908 and the other in 1910, and to the writer's knowledge, not the slightest settlement of the foundation has occurred. Both bogs were so bad that it was impossible to drive a horse across them, and even a man jumping would shake them for a radius of 50 feet."

Old Pavements as Foundations. In New York City old stone block pavements have been used as foundations for asphalt pavements. There are many places on Broadway and in other parts of the city where this experiment has been tried. In some cases, in order to provide room for the asphalt surface, the blocks were taken up and relaid on their sides, and some engineers maintain that a great deal of the repair work on the asphalt pavements in these places is due to the fact that there is more

* See Proceedings, Am. Soc. C. E., April, 1912, page 550.

or less movement to the blocks. On the other hand, some good results have been secured where the old block pavement was not disturbed. As a general rule, however, it is not advisable to use any other than a well-constructed concrete foundation under any type of block, brick, or bituminous pavement, with the exception of certain types of bituminous pavements constructed by the penetration and mixing methods, which will be discussed in later chapters.

Bituminous Concrete Foundations. A bituminous concrete foundation has been used to some extent as a substitute for a hydraulic cement concrete foundation for asphalt and other bituminous pavements. Probably the first construction of this kind was used in Washington, D. C., from 1872 to 1887, when coal-tar pavements were laid quite extensively in that city. In Omaha, in 1891, a 6-inch bituminous foundation for an asphalt pavement was built of broken stone and gravel thoroughly mixed with asphalt. Foundations of a similar character are sometimes used today. They are not as strong, however, as those of hydraulic cement concrete and have the further objection that the wearing surface cannot be removed without disturbing the foundation.

Foundations for bridges and sidewalks will be considered under the chapters especially devoted to these subjects.

CHAPTER VII

EARTH AND SAND-CLAY ROADS

Occurrence. According to statistics obtained in 1909 by the Office of Public Roads, earth roads comprise about 90 percent of the total road mileage in the United States or 2,000,000 out of 2,200,000 miles. Although many of the States are spending large sums of money in constructing highways with a broken stone or gravel surface, it is obvious that the improvement of the total mileage in this manner is a stupendous task. The construction and maintenance of earth roads is therefore of great importance, particularly in those sections of the country where money or good road-building materials such as stone and gravel are wanting. In some States, in fact, the solution of the good-roads problem at the present time is based mainly upon the successful construction and maintenance of their earth roads. The labors of those who have made the improvement of earth roads a serious study have led to the construction of sand-clay roads in certain sections. This type has been built with varying degrees of success in different parts of the country so that in 1909 the mileage in the United States was about 24,500, distributed as follows: about 50 percent in the Southern States, about 20 percent in the States of Michigan, Minnesota, and Wisconsin, and 10 percent in the States of California and Washington.

Soils

The formation of soils and their classification has previously been given in Chapter VI, hence in this chapter only their relation to the construction and maintenance of earth roads will be considered. The soil conditions in different parts of the country and even in restricted localities are so variable that what may be an advisable method of construction in one place

will not serve at all in another. Therefore a careful examination of the soils found is essential.

Sand. Sand is practically the only soil that makes a better road surface in a wet than a dry condition. This fact is well illustrated by the wet sand on a beach between the low and high water marks. It is possible to draw heavy loads over this surface without difficulty. A sandy road when dry, however, offers about as much objection as a road of clayey soil when it is wet.

Clay. Clays are of two kinds, ball clay and slaking clay. The ball clay is extremely plastic, and, as its name implies, tends to ball or lump up. It will keep its shape even if immersed in water for some time. A slaking clay, on the other hand, does not have this same power of plasticity and is more crumbly in its nature, and more readily miscible with water. Although this property is an advantage from the standpoint of its use in road construction, it is apparent that the slaking clays do not have the binding powers contained in the ball clay. A soil which is largely composed of clay acts just the opposite from sand under different climatic conditions, as might be inferred from what has been stated relative to sand. In dry weather the surface becomes hard, and if kept in proper shape makes a good surface. In continued wet weather, however, the water soaks into the clay and softens it, with the result that the surface no longer can support the traffic.

Sand-Clay. An earth road in which the surface is composed of a soil that is a mixture of sand and clay will be much more satisfactory, under most conditions, than one composed of either of these soils alone. There are many places throughout the country where a top soil is found which is a mixture of these two materials and serves to make an excellent road of this kind. A suitable top soil is described by Professor C. M. Strahan,* M. Am. Soc. C. E., as follows:

"It is the top-layer of soil on a cultivated field (or one formerly in cultivation) which has been intermixed and pulverized and

* See Municipal Engineering, December, 1910.

exposed to the action of the weather and of plant life. Usually it shows the results of this action in being bleached out and is of a different consistency from the subsoil below.

"It must be a mixture of clay and sand or gravel. Rocks more than 2 inches in diameter should be shovelled aside in loading, or discarded when dressing the road. Very fine sand is objectionable. Samples separated in a nest of six sieves (graded from 10 to 100 mesh) which show much fine sand below the 40-mesh sieve should be rejected, as they will usually be deficient in clay. The coarse sand and gravel should be at least 50 percent of the mass, and of hard, tough consistency, not readily crushed by traffic. Mica in any considerable quantity damages the soil for road purposes. Soft, black soils with large amounts of humus are entirely unsuitable. When separated by pulverizing and sifting, the contents of the finer sieves, when mixed with water, should give a sticky, smooth ball of nearly pure clay."

Where a suitable soil is not found ready to use, it is possible to mix a sand and clay together on the road. The success of a sand-clay road depends largely upon the selection of the clay. Practically all clays have a tendency to shrink when dry and to expand when wet, and if climatic conditions are such that the road is alternately wet and dry, its effect will be detrimental to the road, particularly if too much clay has been used in the construction. The theory of the sand-clay road is that the voids between the grains of sand in the wearing surface should be entirely filled with clay. This involves mixing the two materials together, a process which is carried out on the road. Although a clay which will readily mix is desirable, the binding power should not be sacrificed to too great an extent in seeking the former quality. The best clay to use will be one which slakes sufficiently to enable the lumps to be broken up, but which is plastic enough to cement the sand together and form a smooth and impervious surface. To find the approximate percentage of clay to be added to the sand, a rough determination of the voids in the sand can be made by taking a known volume of sand and finding how much water can be poured into the same

space that the sand occupies without running over. This amount of water represents approximately the volume of voids. The percentage of materials obtained in this way cannot be strictly adhered to, however, in actual construction, since the sands and clays are very variable in character and it will be found that more clay will be found necessary in one place than in another, or that more sand will have to be added to take up an excess of clay.

Construction

Drainage. One of the principal faults with a large majority of the earth roads in this country is that they are not properly drained. The want of proper drainage allows the surface to become soft after rains and at times when the frost is coming out of the ground, with the result that the traffic soon cuts through and in some cases the roads become practically impassable. If subdrains are employed in an intelligent manner, if the surface is kept shaped up so as to throw the water to the side ditches, and if the culverts are properly constructed and maintained, there is no difficulty in making an earth road readily passable at all times of year to the traffic for which this type of road is suitable. Methods of constructing subdrains have been fully described in Chapter V. The surface drainage is accomplished by means of the longitudinal grade, the crown of the road, and the side ditches. Figs. 38 and 53 show typical

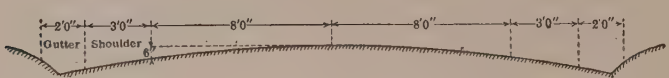


Fig. 53. Cross-section of Earth Road.

cross-sections of earth roads. Since the surface of an earth road is not as impervious as those constructed with a material such as stone or gravel, it is generally given more crown. A crown of about 1 inch to the foot is common, the surface being shaped to follow a circular or other curve or else formed by two or more intersecting planes.

Grading and Wearing Surface. In constructing an earth road the improvement of the grade is generally undertaken. The proper time to begin this work is as soon after April 1st as possible. Frequently the grading is undertaken so late in the year that the new surface does not have sufficient time to get compacted before winter arrives, with the result that the road is in a bad condition all winter. The following directions are taken from a bulletin issued by the State Highway Commission of Minnesota:

"All earth roads on level ground shall be at least 20 feet wide between ditches, and the bottom of the ditches shall be at least 1½ feet below the traveled surface at the center, and the ditches shall be at least 5 feet in width on top. No sod or vegetable or organic matter of any kind will be allowed in the roadbed, but all such matter must be entirely removed and either wasted or used for filling, and must not in any case be deposited within 3 feet of the surface grade line. Sod need not be removed from under the fill, but it must be taken from the top of surface ditches before the road grader is used to round up the roadway. All ditches must be made continuous and have a uniform slope to some permanent line of drainage. Side drainage must be provided for where necessary, and such drains must be kept open at all seasons of the year. All new roads must be rolled if a roller is available; if not, they must be kept smooth by the use of a road drag until well consolidated by travel.

"Where it becomes necessary in a rolling country to excavate ditches deeper than 1½ feet, the distance between the ditches must be increased so as to provide for perfect safety to teams obliged to turn out to one side of the center of the roadway. On marsh fills the distance between ditches shall be not less than 40 feet, and should be 50 feet if the height of fill will permit, the object being to provide a berm for winter travel.

"On a level or nearly level prairie the roadbed should be built up a foot or two above the original surface, to provide suitable drainage from the center of the roadway to the ditches, and the crown of the road should be sufficient to allow the water from the rainfalls to be quickly carried off. The crown should not

be less than 6 inches on a 16-foot roadway, and may be made somewhat more when the road is newly built, to provide allowance for future flattening out.

"On all fills it is generally assumed that the earth will stand on a slope of 1½ to 1—that is, for a 4-foot fill each slope will occupy 6 feet of space outside the roadbed. In cuts the slope will vary with the class of material. A sandy loam requires a slope of 1½ horizontal to 1 vertical, and in cases where it becomes necessary to use more earth for the fills it would be advisable to make the slope 2 or even more to 1.

"On such a slope grass will grow well and aid in preventing wash and wear. In clay cuts a slope of 1 to 1, or 45 degrees, will stand very well. The writer has found that in solid, compact clay without sand seams, for cuts of 8 feet or less, a vertical bank is better than any slope and will stand longer and better under the action of rain and weather, especially where rain-water reaches the roadbed from the sides. The result of heavy rain and side drainage on slopes is to gully the slopes and fill the side ditches, and where there is no slope there is little or no wash. In cases where the cut is made vertical, the side ditches may be made some distance from the foot of the cut so as to allow for what slight wash and wear there may be from the sides. The sides of all cuts or a sloping surface should be protected by a ditch a few feet back from the edge of the cut, so as to carry side drainage off to the ends of the cuts, and not allow it to find its way to the road drains. This is important whether the cut is vertical or sloped. In many cases a single furrow cast over towards the edge of the cut will be sufficient to prevent surface water from reaching the roadway.

"In making sidehill cuts it would be better to have the entire roadbed in the cut, and this may generally be arranged for by setting the grade line so as to provide the proper amount of earth for filling, but if that is not needed the roadbed may be made partly in excavation and partly in embankment.

"In making such a roadbed it must be remembered that the portion on the downhill side will be very apt to settle while the portion on the uphill side will remain solid, and this

will result in a break at the center. Now if the fill is placed on the original surface the chances are that that portion of the road on the fill will slide, especially if the material be of a clayey nature. To prevent this, run furrows along the slope parallel with the center line of roadway, or on very steep banks cut it into steps, first removing the sod where the filling is less than 3 feet in depth."

It has been the experience of engineers in the Province of Saskatchewan, Canada, in building earth roads across swamps and sloughs, that the fill should be made at least 16 feet wide, with a level crown, and that the crown must be at least 16 inches above the high-water mark, to prevent traffic from breaking through. Small poplars, willows, or brush, laid with the butt ends outward and the branches overlapping at the center, are sometimes laid down before the fill is made. In cases where the fill is to withstand wash or wave action, the side slopes may be riprapped or the fill may be constructed of alternate layers of brush and earth.

In some parts of Canada the prairie sod will satisfactorily support a light traffic. Where the traffic is so heavy that it cuts through the sod and where the topography is such as to warrant grading the road, the tough mat of soil is not disturbed for a strip of 8 feet in the center of the roadbed, since it serves as an excellent foundation for the filling that may be put upon it.

Sand-Clay Roads. Many miles of roads in Clarke County, Georgia, have been surfaced with from 10 to 14 inches of top soil, consisting of a mixture of sand and clay taken from the adjacent fields. The surface is shaped up with road machines and given a crown of 1 inch to the foot. The surface is consolidated by the traffic alone.

If a sand-clay road is to be constructed of a sandy subsoil, the roadbed is shaped up to the desired crown. The clay is brought on to the road and spread in a layer of 6 to 8 inches at the center, tapering off to a thin layer at the sides. If the construction is begun at the end of the road near the source of supply of the clay, the road will be somewhat compacted during construction by the teams on the work. It is necessary

that the clay be thoroughly mixed with the sand and that all lumps should be broken up. Dry mixing or covering the clay layer with sand and leaving it for traffic to mix and compact will not secure as quick and as good results as can be obtained by plowing, harrowing, and rolling. The clay should be puddled to get a thorough mix with the sand and hence water is essential to obtain the best construction. If no water is at hand, the mixing can be completed soon after or during rainy weather.

If a sand-clay road is to be constructed of a clayey subsoil, the roadbed is shaped up and drained as in the previous case. The surface is then plowed and pulverized as much as possible to a depth of 4 inches. This surface is covered with a layer of sand 6 to 8 inches thick. In this case the mixing of the clay and the sand should be carried out while the materials are in a dry state. After this preliminary mixing has been accomplished, the further mixing is carried out when the road is wet and the road finally shaped up and compacted.

It must not be expected that as soon as a sand-clay road is first completed it will give a perfect surface. It is only by carefully watching the road and adding sand or clay as required that a surface will finally be obtained that is satisfactory.

Earth Shrinkage. It is important in the measurement of grading operations to distinguish between loose measurement and measurement in place. All estimates are generally based on the assumption of material in place. It is a well-established fact that earth when removed from its original position in a bank increases in bulk, or swells. It is also a well-known fact that when the excavated material is placed in a fill it will shrink and settle so that it will occupy a smaller space than it did originally. The swelling on removal from the original bank will vary generally from about 8 to 14 percent, but in some cases may be as high as 40 to 50 percent. The shrinkage is very variable and depends upon the kind of earth, the manner in which the embankment is made, and the climatic conditions.

H. P. Gillette, M. Am. Soc. C. E., states that "Clean sand and gravel swell 14 to 15 percent; loam, loamy sand on gravel swell 20 percent; dense clay and dense mixtures of gravel and

clay 33 to 50 percent, ordinarily about 35 percent; while unusually dense gravel and clay banks swell 50 percent."

The same authority says with regard to shrinkage, in considering the different means of compaction, namely, puddling action of water, pounding of hoofs and wheels, artificial rolling, that "If the puddling action of rains is the only factor, a loose mass of earth will shrink slowly back to its original volume, but an embankment of loose earth will at the end of a year be still about 8 percent greater than the cut it came from.

"If the embankment is made with small one-horse carts or wheel scrapers, at the end of the work it will occupy 5 to 10 percent less space than the cut from which the earth was taken, and in subsequent years will shrink about 2 percent more, often less than 2 percent.

"If the embankment is made with wagons or dump cars and made rapidly in dry weather without water, it will shrink about 3 to 10 percent in the year following the completion of the work and very little in subsequent years.

"The height of the embankment appears to have little effect on its subsequent shrinkage."

Tools and Machines. Grading is accomplished by a variety of tools and machines, a brief description of which, together with their uses and cost, follows:

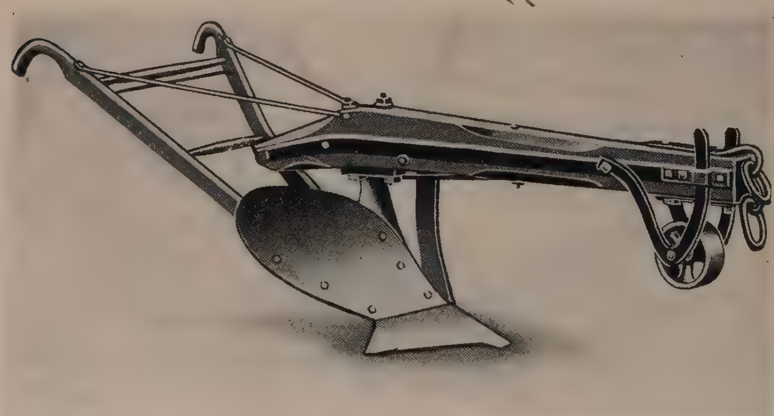
Picks. The pick may be pointed at both ends or it may have one end flattened to a chisel point, to be used in trimming up slopes of cuts. The pick head weighs from 7 to 9 pounds and is made of a high grade steel, the points being made of crucible tool steel. An average price per dozen f. o. b. Chicago for pick heads is about $6.00. Pick handles cost from $1.50 to $3.00 per dozen, depending upon the selection and finish of stock.

Shovels. A pointed shovel with a short "D" handle is the one most commonly used in grading operations in this country. In Europe the same style of shovel with a long, straight handle is more in favor. Square-pointed shovels are better adapted for mixing either cement or bituminous concrete, and for handling sheet asphalt mixtures. Scoop shovels are used to advan-

tage in street-cleaning operations, for handling sand or other fine material, and for removing snow. Shovels are made in different sizes and of different grades of steel, the blades having either a black or a polished finish. The following table * gives prices for shovels with black-finish blades. Shovels with square or round points with "D" or long handles are the same. A No. 2 shovel is the size generally used. For a polished finish add 50 cents:

Size	Width of Blade. Ins.	Length of Blade. Ins.	Extra Grade Per Doz.	1st Grade Per Doz.	2d Grade Per Doz.	3d Grade Per Doz.
2	9½	11¾	$9.90	$8.70	$7.20	$5.70
3	9¾	12¼	10.20	9.00		
4	10½	12½	10.50	9.30		

Mattocks and Bush Hooks. Mattocks are used mainly for trimming up slopes, for loosening soils full of roots, and around



Courtesy of the Good Roads Machinery Co.

FIG. 54. Grading Plow.

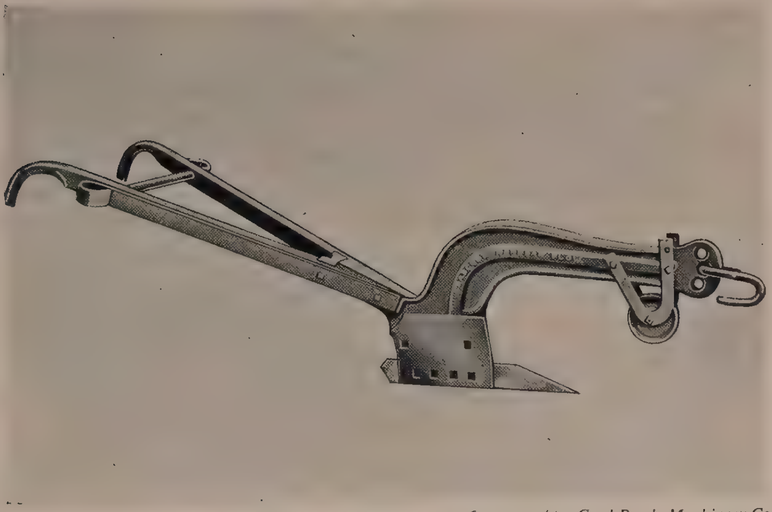
stumps. The heads weigh about 6 pounds each and cost about $4.00 per dozen f. o. b. Chicago. Handles are the same price as pick handles.

* See Engineering-Contracting, April 5, 1911.

Bush hooks are used mainly in clearing away brush and small undergrowth.

Hoes and Rakes. Hoes and rakes are principally used in shaping up the surface. Hoes are also used in street-cleaning operations. They cost about $6.00 per dozen with 6-foot handles.

Plows. The essential parts of a plow are the beam, clevis, handles, share, mold board, and wheel or shoe. The beams are made of either wood or iron, the latter being preferable



Courtesy of the Good Roads Machinery Co.

FIG. 55. Rooter Plow.

where a plow is going to be continually exposed to the weather or is intended for use in stiff material. The share and mold board are so made that the furrow may be turned either to the left or to the right. The function of the shoe or wheel near the front end of the beam is to regulate the depth plowed. An ordinary grading plow weighs about 150 pounds. It will plow a furrow about 10 inches wide and from 6 to 12 inches deep. The price of a plow of this type (see Fig. 54) is about $16. For breaking up hardpan, old macadam, or other stiff material, a rooter plow, as illustrated in Fig. 55, is employed. This plow

is generally made with an iron beam. The point is made of a high carbon tempered steel and is sometimes doubly reversible. A plow of this kind is best pulled by a steam roller or a tractor. If horses are used it may require from six to twelve, depending upon the material plowed. The average price of this type of plow is about $30 and extra points cost $6.00 each.

Wheelbarrows. Wheelbarrows are made either of wood, steel, or with a wooden frame and steel bowl. The wooden form is more commonly used in Europe and possesses some advantages over those built with a steel bowl or all of steel. First, it is cheaper; second, it is more cheaply kept in shape and is much better adapted for quarry work, where a steel bowl is liable to become much abused by having stone thrown into it; third, it is somewhat lighter than the other two. On the other hand, if it is desired to handle a semifluid material or a concrete or bituminous mixture, a barrow with a steel bowl will serve the purpose much better. The weight of a wooden wheelbarrow is about 60 pounds and of an all-steel barrow 75 to 80 pounds. They are made in different sizes, those having a capacity of 3 to 4 cubic feet being generally used. A wooden wheelbarrow costs about $2.00. One all made of steel costs about $7.00.

Drag Scrapers. A drag scraper, as shown by Fig. 56, consists of a pressed steel bowl to which a bail and handles are attached. Sometimes the bottom of the bowl is reinforced with a double bottom or with two pieces of strap iron which serve as runners. They weigh from 75 to 100 pounds, and are made in several sizes, generally listed in catalogues to hold 3, 5, and 7 cubic feet. These capacities, however, are figured on the basis of loose measurement and for a scraper heaped full. In actual work the size represented to hold 5 cubic feet will hold from 3 to 4 cubic feet. This form of

Courtesy of the Good Roads Machinery Co.
FIG. 56. Drag Scraper.

scraper wears out very rapidly on its cutting edge and on the bottom, particularly when working in hardpan or gravel. Drag scrapers cost from $4.00 to $5.00 each.

Method of Operation. In operating a drag scraper, it is usually drawn by one or two horses. To load, a man grasps the handles and pushes the cutting edge down into the loosened earth as the scraper is pulled along. Then the full scraper is dragged along on its bottom to the point of dump, where either the driver or a dump man takes hold of one or both of the handles and lifts the scraper so that it turns upside down about its cutting edge.

Wheel Scrapers. A wheel scraper, Fig. 57, is similar in shape to a drag scraper, but the bowl is fixed to two wheels fitted with a pole and is usually drawn by two horses. They weigh from 400 to 700 pounds and are made in sizes of 9, 12, and 16 cubic feet capacity which, according to Gillette, hold 6, 7, and 11 cubic feet respectively of place measurement. They cost from $25 to $50.

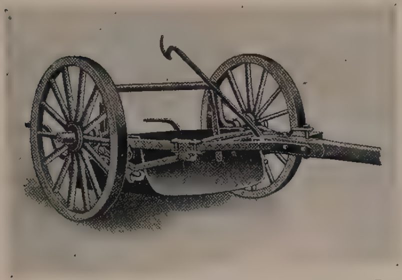


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FIG. 57. Wheel Scraper.

Method of Operation. A wheel scraper is operated as follows: As it is pulled through the plowed material in its lowered position, a man grasps the small handles at the rear of the bowl and tilts the bowl so that the cutting edge engages with the earth. When the scraper is full, he pulls down on the long lever which is seen at the rear, which raises the bowl from the ground. The lever is locked by a catch and the scraper is hauled to the dump. To dump, a man pushes up on the long lever, which makes the cutting edge drop to the ground and causes the bowl to turn upside down about the axle. On the small-size scrapers no snatch team is used, on the medium size a snatch team is generally used, and on the large size a snatch team is always used. A snatch team is one or more pairs of horses, which are

hitched to the pole in front of the team dragging the scraper during the process of loading.

Four-Wheel Scraper. A four-wheel scraper, somewhat similar to the two-wheel scraper, is manufactured in which the front and rear wheels do not track, thus serving to compact the fill during the process of grading. The capacity of the bowl is about 1 cubic yard loose measurement and it costs $260.

Method of Operation. The principle of operation is about the same as that of a two-wheel scraper with the exception that the driver, who rides on the scraper, controls the levers which load and dump the scraper. The scraper is drawn by horses. Sometimes, however, they are used in trains, the train being drawn by a traction engine. It is claimed with this scraper that, if a traction engine is used, it is not necessary to plow except in the case of the most compact soils. In dumping the load it spreads the materials in layers of any desired thickness.

Buck Scrapers. This type of scraper is also known as a Fresno Grader. It consists of a bowl or scoop, which is about 13 inches high, 18 inches wide, and from 3 to 5 feet in length. It weighs from 255 to 325 pounds, depending upon the size. Since the earth is pushed along in front of the bowl, the capacity will vary, depending upon the material being moved and the size of the scraper. In any event it is more than the actual measurement of the bowl. For instance, the actual measurement of the bowl above described, 5 feet long, is about 8 cubic feet, but loads have been drawn by this size scraper of about 19 cubic feet, loose measurement, when working in a clayey earth. Buck scrapers cost about $20, the difference in price for the various sizes being negligible.

Method of Operation. The size described above is generally drawn by four horses and loads and dumps in a similar manner to wheel and drag scrapers. When the load is dumped, the scraper rests on runners which are fixed at either end and is thus dragged into position for reloading.

Carts and Wagons. A one-horse tip-cart is generally built

with two wheels. To dump, the body tips over the axle, thus discharging its contents. The bodies have about 21 to 24 cubic feet of space, without side boards. The cost of this type of cart is about $45.

Two-horse tip-carts are operated on the same principle, but are built on four wheels. They hold about 1½ cubic yards of material, loose measurement. The front wheels are made smaller so as to cut under the body and thus facilitate turning

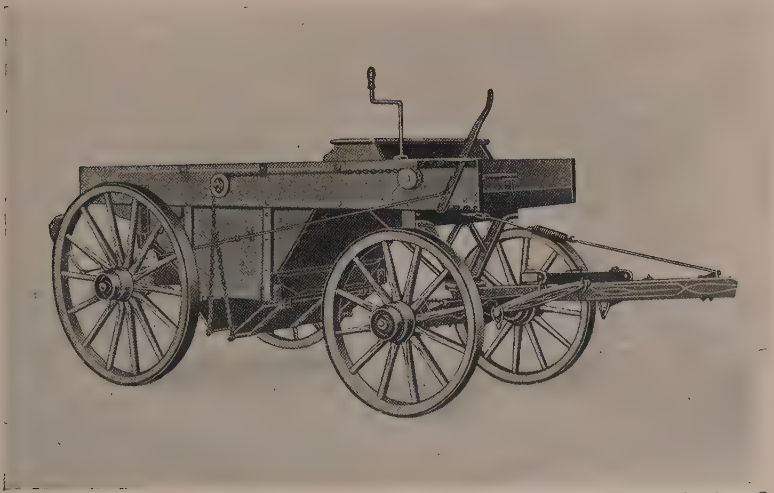

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FIG. 58. Patent Bottom Dump-Wagon.

the cart around in a short space. This cart costs about $100. A tip-cart used to a considerable extent by contractors is similar to the two-horse tip-cart, except that the box sets further towards the front wheels. In dumping this wagon the box is pushed towards the rear and when its center of gravity is beyond the rear axle, it tilts and dumps. As there are rolls between the box and the truck frame, one man may easily dump the wagon, whereas with the ordinary two-horse tip-cart it requires several men to dump the wagon when it is heavily loaded.

Slat bottom dump-wagons consist of a box fixed to a four-

wheeled truck. In order to dump the load the movable slats, generally made of 2 by 6 inch boards, which comprise the bottom, are removed one by one until the load is dumped. The only advantage of this type of wagon is that the wagon box may be cheaply replaced.

Patent bottom dump-wagons are made in 1, 1½, 2, 2½, and 3 cubic yard sizes. The bottom of the wagon is made up generally of two leaves, hinged either to the sides or to the ends of the box. Fig. 58 shows the latter type. These doors are held in place with chains which are wound up on a windlass operated by the driver. To dump the load the driver with his foot kicks a release lever and the doors fly open, thus discharging the load. The doors are closed by the driver turning the windlass. While the body of the wagon is generally made of wood, the bottom doors are sometimes made of wood and sometimes of sheet-iron. One of the doors is usually provided with a lip which overlaps the joint formed by the doors and thus prevents material from sifting through. All types of these wagons are built to withstand extremely rough usage. They are not only suitable for grading work, but also are excellent for hauling stone, etc. The average weight of the wagon is about 2,000 pounds. The chains which control the movement of the doors are sometimes provided with grab hooks, which can be shifted on the chain so that the doors will only drop part way open as desired. The front wheels cut under the body. Prices for these wagons vary depending upon the size, the range being from about $115 to $200.

Road Drags. One of the simplest and cheapest forms of road drags is the split-log drag. It is a home-made tool, but is extremely useful in maintaining an earth road, and is today preferred by many to the steel drag. A dry red-cedar log is best, although red elm, walnut, box elder, soft maple, and willow make good drags when thoroughly dry. Oak, hickory, and ash are not generally recommended. A log should be from 7 to 8 feet in length and from 10 to 12 inches in diameter. A wind in the log, provided it is not more than 4 inches in 8 feet is not detrimental. The log is split as nearly in half as is prac-

ticable, and the heaviest and best slab is used for the front log. The logs are braced together as shown in Fig. 59. The diagonal brace at the end runs from the middle of the back log to within 1 inch of the bottom of the front log. An iron strip is fixed at the ditch end, as shown, and it projects ½ inch below the lower edge of the slab at its outermost extremity and is

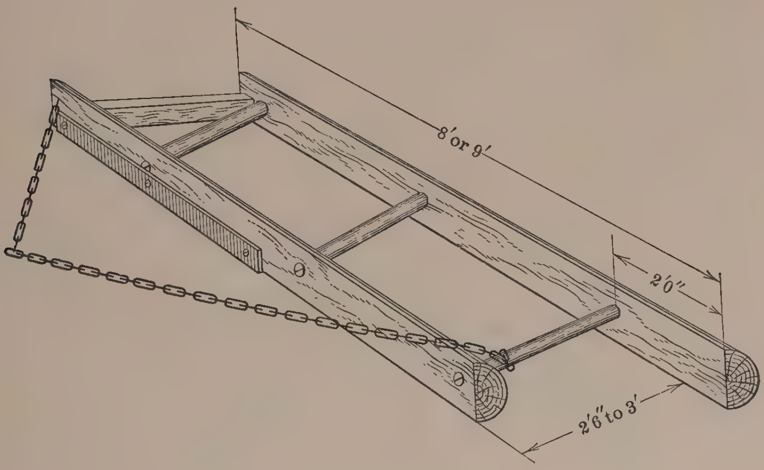


FIG. 59. Split-Log Drag.

flush with the slab at its other end. If the front log stands plumb on the face, the iron strip may be wedged out, or if the log has a wind in it, this may be taken advantage of in giving the iron strip a pitch. A platform of 1-inch boards is placed over the cross braces on which the driver stands. The boards of the platform are fixed about 1 inch apart to allow any dirt that comes onto the platform to sift through onto the road again. The chain is put through the middle of the log at the ditch end and passed over the top of the log at its other end and fastened to the brace. This allows the dirt to pass underneath the chain as it runs from the ditch along the log to the center of the road.

A plank-log drag is built in a similar manner to the split-log drag except planks set on edge are used in place of the split

logs, the planks used being 10 to 12 inches wide and 2 to 4 inches thick.

A lap-plank drag, shown in Fig. 60, is used for smoothing up a road where only a small amount of material is to be moved.

Various forms of steel road drags are now manufactured, which have about the same over-all dimensions as the split-log drag described above, the logs or planks being replaced by angle irons or steel plates placed on edge. They weigh considerably more than split-log or plank drags, and for this reason are not preferred by some. Steel drags are often equipped with a lever by means of which the blades can be tilted at any desired angle. Some steel drags are made with three parallel blades instead of two and are provided with braces, which, when the drag is turned upside down, serve as runners on which it may be drawn from point to point. Another device which is furnished with one type of steel drag is a so-called "never slip" attachment. It is nothing more than a seat for the driver

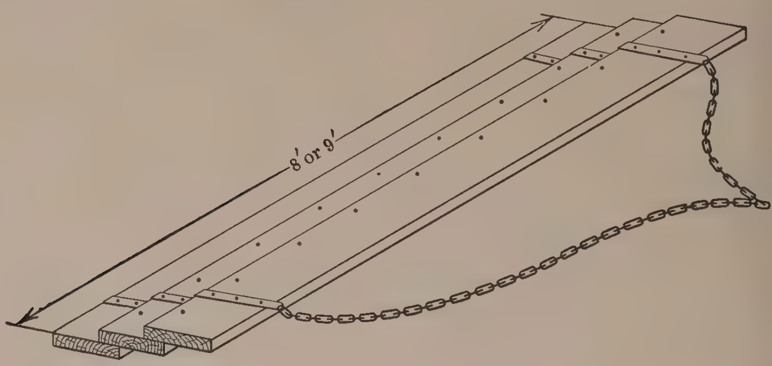
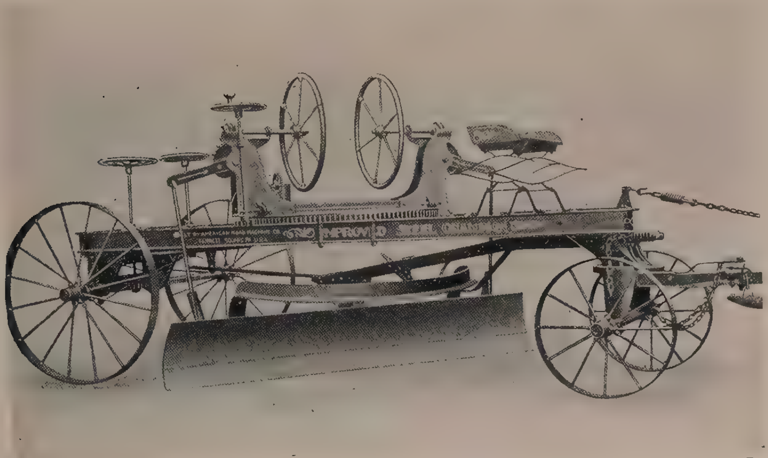


Fig. 60. Lap-Plank Drag.

which is attached to an arm extending out back of the drag. The seat is supported by braces to a vertical blade, which acts something like a rudder and tends to keep the drag in place when working. The prices of steel drags vary from $8.00 to $25.00, depending on the type, the last price being that of the drag fitted with the "never slip" attachment.

Method of Operation. The team is hitched to the chain so that the drag will be pulled along the road without a load at an angle of about 45 degrees with the center line, the ditch end always being ahead. If it is desired to make the drag cut deeper, the chain should be lengthened as it is obvious that the nearer the team is to the drag, the more the tendency to lift it from the ground. The driver generally stands on the drag, when working, and by shifting his weight from one end to the other causes the drag to cut into the soil or to drop the soil being carried along by it. To cut he shifts his weight mostly on the front runner towards the ditching end; to cut light he shifts his weight towards the rear runner; to drop the earth carried



Courtesy of the Good Roads Machinery Co.

FIG. 61. Four-Wheel Road Scraper.

along into a depression, he suddenly shifts his weight to the rear and towards the end of the drag nearest the center of the road. Some of the steel drags are so heavy that they cannot be operated in this manner, and hence are not so adaptable to the work.

Road Scrapers or Graders. There are several different types of road scrapers or road hones. The four-wheel machines, Fig. 61, have blades from 7 to 8 feet long made up of two parts,

a cutting edge and a mold board. The blade is suspended from a part or a full circular frame attached to the machine. By turning the large wheels, the blades may be tilted at any desired angle with the vertical. It is also possible to turn the blade through any desired horizontal angle; in fact, in some machines the blade can be turned through a full circle. Such machines are generally called reversible scrapers or graders. In some types of machines the blade is given a forward or backward tilt by attachments fixed directly to the blade, while in others the blade is fixed in this respect, and the tilt is obtained by lowering or raising the front end of the frame over the front axle. It is also possible in some types to shift the blade sideways so as to project beyond the wheels for some distance, which is a great convenience in filling in ditches or cutting down banks. The framework is generally made of steel shapes, although wood is sometimes used. Another feature of many of the four-wheel machines is that the rear axle is made telescopic so that either wheel may be shifted in a lateral direction. This adjustment enables the rear wheels to straddle a furrow or to engage with the side of the bank and thus prevent side slip. In some makes the rear axle is pivoted so that it will turn through a small horizontal angle, helping the machine to keep in place when in the center of the road. There are some types also in which the rear wheels are so fixed to the axle that they may always be made perpendicular to the slope on which the machine is travelling. All of these different adjustments are carried out by one man, who stands on the rear of the machine and operates the various wheels and levers which are within easy reach. A four-wheel machine weighs about 3,000 pounds and an approximate average price would be about $250 f. o. b. factory.

Various types of two-wheel scrapers are also manufactured. In these machines the blades are not as long as in the four-wheel type. The blades do not have the same ranges of movement as in the larger machines, and all the levers are worked by the man that drives the team. Flanges are usually provided on the wheels to prevent the machine from slipping side-

ways. This type of machine weighs from 600 to 800 pounds, the approximate cost being $150.

Method of Operation. In constructing a road by means of a scraper the dry grass and sod is first burnt off. A cut is then made at the edge of the ditch, using the point of the blade, the latter being set at a sharp angle so that only the point and a very short length of the blade comes in contact with the ground. On the next round the blade is lowered to a flatter angle and the

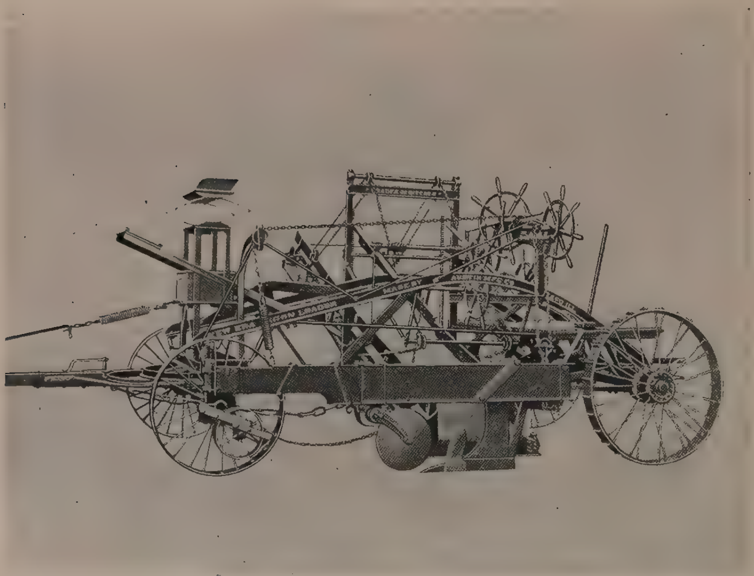
Courtesy of the Austin Manufacturing Co.

FIG. 62. Road Scrapers Drawn by Tractor.

earth is moved along the blade towards the center of the road. By making several rounds of the scraper in this manner the road is crowned up at the center. To smooth out the road the surface is first thoroughly harrowed to break up large lumps, and then the scraper is drawn along the road with the blade set at right angles to the center line of the road. When a reversible machine is used the blade is turned around so that the convex

side is ahead. A plow is not necessary in scraper work, since the machine can generally do all the plowing desired with the point of the blade. In order not to get a soft road it is not advisable to move the dirt up with the scraper in layers over 4 inches deep.

In some cases from one to three furrows are plowed at the ditch side of the road, the material being turned towards the



Courtesy of the Austin Manufacturing Co.

FIG. 63. Elevating Grader.

center. The scraper is then set to work at the furrow nearest the center, and it moves over from this furrow towards the center only about as much dirt as is loosened by the first round of the scraper. The next furrow is moved over in a similar manner, and the process is repeated until the last furrow is reached, which is moved over in turn. The road is then smoothed out.

The four-wheel machines for heavy work require from four to six horses, whereas two horses are used when the work is light. Fig. 62 shows two machines being worked in unison and

drawn by a traction engine. On the lighter two-wheel machines from two to four horses are necessary, depending upon the character of the work.

The advocates of the four-wheel scraper claim that it is difficult to keep the lighter two-wheel machines in line, and that also the blade is not held as steady as in the heavier four-wheel machines, and an uneven surface in the road results. On the other hand, those who prefer the two-wheel machine claim that practically the same amount of work can be done per day as with the larger machines and at a much smaller operating cost.

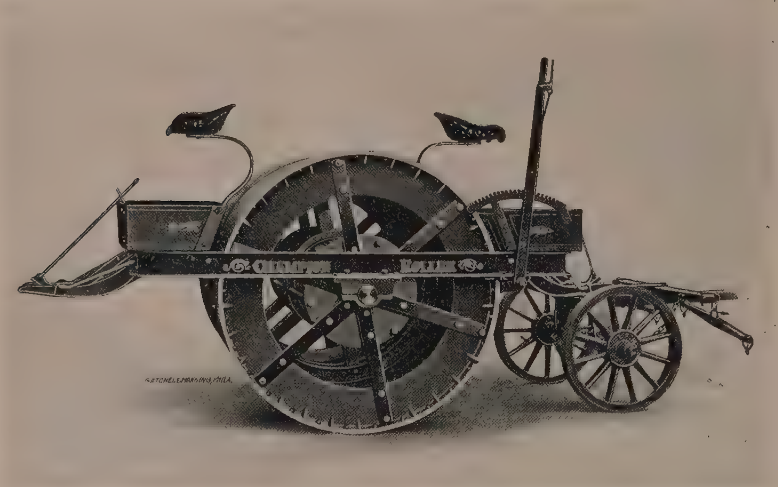
Elevating Graders. The principal parts of the elevating grader shown in Fig. 63 are the plow and mold board, the elevating belt, and the trussed frame by which the belt and plow are supported. In the type illustrated the plow is pointed and is carried on a heavy channel beam at one side of the machine to counterbalance the weight of the elevating belt on the opposite side. A disk plow is sometimes substituted for the pointed plow. The mold board back of the plow is shaped so as to deliver the furrow to the elevating belt with as little loss as possible. The elevating belt carriers are made in 3 to 5-foot sections, so that any length from 15 to 30 feet in some of the larger machines can be obtained. The carrier is run either with gears driven by the wheels or by a gasoline engine set on the rear of the grader. When the carrier is driven by an engine it requires less power to haul the machine. An elevating grader costs about $1,000.

Method of Operation. For heavy work the grader requires twelve horses, eight being hitched in front and four in the rear, two drivers and two operators on the machine, who operate the various levers controlling the movements of the plow and belt. A 25 H. P. traction engine may be used in place of the horses. The grader, as it moves along, plows up the earth, which is thrown onto the elevating belt and discharged over its end and either onto the road or into wagons, which travel alongside of the grader.

Rollers. Steam-rollers will be fully considered in Chapter

IX, since they are used more in the construction of stone roads than those built of earth.

A horse roller is generally made with one large roller having a face of about 5 feet and a diameter of about 5 feet. Any weight desired from 2½ to 5½ tons, varying by 1 ton, can be obtained. Additional weight may be placed in the boxes at either end of the frame and the weight be increased by 1 ton



Courtesy of the Good Roads Machinery Co.

FIG. 64. Horse Roller.

in this manner. The roller is made of steel or cast iron. An essential feature of a horse-drawn roller is to have it reversible, so that it can be drawn in either direction. In Fig. 64 the two-wheel truck may be uncoupled and attached to the opposite end of the roller. In some types, however, the pole is attached to only one wheel, which is fixed to a cast-iron arm, which turns about a pin fixed to the top of the machine. A grooved roller is sometimes specified, due to the fact that better compression can be obtained than with the smooth-faced roller. The grooves are formed by bars bolted around the face of the roller parallel to the edges and at a small interval apart. The price of horse rollers varies from $300 to $450, depending upon the size, an average price being from $70 to $90 a ton.

Classification of Grading. Before considering the cost of grading operations, it is essential that something be said in regard to grading classification. In Chapter VI, the different kinds of soils were described under the terms gravel, sand, clay, marl, loam, peat, and muck. It is quite common in grading specifications to classify the materials to be excavated as earth, hardpan, loose rock, and solid rock: earth to include clay, sand, loam, gravel, and all hard material that can be reasonably plowed, and all earthy matter or earth containing loose stones or boulders intermixed, and all other material that does not come under the classification of hardpan, loose or solid rock; hardpan to include all material, not loose or solid rock, that cannot be reasonably plowed on account of its own inherent hardness; loose rock to include all stone and detached rock, found in separate masses, containing not less than 1 cubic foot, nor more than ½ cubic yard, and all slate or other rock, soft or loose enough to be removed without blasting, although blasting may occasionally be resorted to; solid rock will include all rock in place and boulders measuring ½ cubic yard and upwards, in removing which it is necessary to resort to drilling and blasting. H. P. Gillette, M. Am. Soc. C. E., subdivides the first class "earth" into three classifications as (1) easy earth, (2) average earth, (3) tough earth. He defines these classes as follows:

"To the first class belong loam, sand, and ordinary gravel, which require little or no picking to loosen ready for shovelling. To the second class belong sands and gravels impregnated with an amount of clay or loam that binds the particles together, making it necessary to use a pick or plow drawn by two horses to loosen the earth before shovelling. To the third class belong the compact clays, the hardened crusts of old roads, and all earths so hard that one team of horses can pull a plow through the earth only with the greatest difficulty, but that two teams of horses on one plow can loosen with comparative ease." It is apparent that the classification of materials encountered in grading depends largely upon the judgment of the engineer, and there are very few large grading contracts completed with-

out frequent disputes arising between the contractor and the engineer with regard to classification of excavation.

Cost of Earthwork. In comparing the cost of moving earthwork by different tools and machines, the following costs should be taken into account: loosening, loading, hauling, dumping, lost time, and depreciation of tools and machines. Since earthwork is generally contracted for as so much a cubic yard in place, place measurement should be used in figuring the cost rather than loose measurement. The kind of material being moved, the organization of the labor, and the location of the work, that is, whether or not there is ample room to load and dump, will all affect the cost of the work, so that only a few general principles can be stated. A large part of the following matter relative to cost of earth excavation has been abstracted from Gillette's "Cost Data" in which book will be found an excellent and very complete treatise of the subject.

The following facts and definitions of terms commonly used are given as they will constantly be referred to:

Lead is a term used to define the distance in a straight line between the center of gravity of the mass in cut and the center of gravity of the mass in fill.

Haul is the actual distance in one direction between these two points.

A man will walk from 200 to 250 feet per minute while pushing a load.

A horse will travel walking at a rate of about 220 feet in one minute. This is an average speed over fairly hard earth roads with allowances for rests and climbing occasional grades. On soft roads this rate will be decreased, and on roads with a hard surface it will be increased. The loads in addition to the weight of the wagon that a team of horses can pull over different kinds of surfaces is given by Gillette as follows:

	Short Tons
Very poor earth road	1.0
Poor earth road	1.25
Good hard earth road	2.0
Good clean macadam road	3.0

Cost of Picking, Shovelling, Plowing. The cost of picking depends upon the kind of earth encountered. Gillette states that "The cost of loosening earth with a pick ranges from 1 cent per cubic yard for very easy earth to 11 cents per cubic yard for very stiff clay or cemented gravel; for average earth the cost of picking is about 4 cents per cubic yard." The above costs based on a wage of $1.50 for ten hours.

The amount of earth that can be moved by a man shovelling depends upon the character of the earth, the way it has been loosened, the size of the shovel, and the distance the material has to be cast. Earth broken down and loosened on the face of a cut may be shovelled and loaded by one man at the rate of 18 cubic yards per ten hours, whereas plowed earth cannot be moved by one man at a much quicker rate than 14 cubic yards per ten hours. Gillette gives as the cost of loosening with a pick and shovelling into wagons, wages being 15 cents per hour:

Easy earth	12 cents per cubic yard.
Average earth	15 " " " "
Tough clay	20 " " " "
Hardpan	40 " " " "

Gillette states that a team on a plow will loosen 500 cubic yards of loam, 350 cubic yards loamy gravel, or 250 cubic yards of fairly tough clay per ten-hour day. The cost of plowing 350 cubic yards with team and driver and one man holding the plow will be about 1½ cents per cubic yard, where wages of team and driver are $3.50 and $1.50 for man holding plow. Plowing very tough material with a rooter plow using four horses and 3 men will cost about 5 cents per cubic vard and 180 cubic yards can be loosened per day.

Cost by Wheelbarrows. Wheelbarrows are not used much in earth excavation for road work except in very muddy places where a team might mire, in narrow confined places, or in moving very stony soils. The ordinary barrow will hold about 1/10 of a cubic yard when pushed by a man on level runways, but in ascending grades only about 1/15 of a cubic yard can be

wheeled. The elements of cost are covered by the rules by Gillette which are quoted under the various methods.

"To a fixed cost of 17 cents per cubic yard, add 5 cents per cubic yard per 100-foot haul, when steep ascents must be made, or 3½ cents per 100 feet when level."

Cost by One-Horse Carts. About 0.4 of a cubic yard per load can be hauled in a one-horse tip-cart over poor earth roads with steep grades. A gang of 4 or 5 men will load 0.4 of a cubic yard in three minutes. It will take one minute to dump the cart. The cost of a man on the dump is included in the following rule:

"To a fixed cost of 19 cents per cubic yard add ¾ of a cent per cubic yard per 100-foot haul."

Cost by Wagons. A gang of men should load 1 cubic yard into a wagon in four or five minutes. It takes about one minute to dump an end dump wagon and three minutes to dump a slat-bottom wagon holding 1½ cubic yards. The time lost in dumping a patent bottom dump wagon is negligible. Assuming the cost of plowing and loading to be 13 cents per cubic yard and allowing 5 cents for cost of lost time of team while being loaded and dumped, the cost of a dump man being included, the following rule results:

"To a fixed cost of 18 cents per cubic yard add ½ cent per cubic yard per 100-foot haul when a slat-bottom wagon is used holding 1 cubic yard."

Cost by Drag Scrapers. The lost time in loading and dumping is from one-third to one-half minute per trip or three and one-half minutes per cubic yard. The cost of a man loading scrapers is ¾ of a cent per cubic yard. The cost of plowing, 1½ cents per cubic yard. A scraper travels about 100 feet extra each trip over and above the lead in making the turns at either end. This is equivalent to one-half minute of the time of the team. The average load is ⅐ of a cubic yard.

"To a fixed cost of 6¼ cents per cubic yard add 4½ cents per cubic yard per 100 feet of lead. The cost of foreman's wages, ¾ of a cent per cubic yard, and depreciation, ¼ of a cent

per cubic yard, will add 1 cent more per cubic yard to the amount obtained by the above rule."

Cost by Wheel Scrapers. One-half minute is lost in loading and dumping. Another one-half minute is lost in making the turns at either end.

"To a fixed cost of 5¼ cents per cubic yard for No. 1 wheelers, or 6¼ cents for No. 2 wheelers, or 6¾ cents for No. 3 wheelers, add the following per cubic yard per 100 feet of lead: 2¾ cents for No. 1 wheelers; or 2⅕ cents for No. 2 wheelers; or 1⅜ cents for No. 3 wheelers. Foreman's wages and repairs to wheelers will add another cent per cubic yard to the above."

Cost by Four-Wheel Scraper. This scraper carries about 1 cubic yard to a load. The time required to load is one and one-quarter minutes. The time required to dump the machine can be neglected. The time used in turning at either end of haul is one-half a minute. A four-horse snatch team is used to help load and a three-horse team is used on the scraper. The fixed cost per cubic yard will be about 3 cents.

To a fixed cost of 3 cents per cubic yard add 1 cent per cubic yard for each 100 feet of haul.

Cost by Buck or Fresno Scraper. A Fresno scraper having a bowl 13 inches high, 18 inches wide, and 5 feet long will carry a load under favorable conditions on level or uphill hauls of about ½ a cubic yard. Working in a clayey earth and on down hill hauls the load may be from 25 to 50 percent greater, while in dry running sand the load may be 25 percent less. Four horses travelling abreast are generally used on this scraper. The scrapers can generally be loaded and dumped by the driver. Fresno scrapers do the work cheaper than the more common form of drag scraper and the economical limit of haul for which this scraper is used varies from 200 to 300 feet, depending upon the kind of material used. If the cost of plowing is taken as 1½ cents per cubic yard, the following rules give the cost of the work where the daily wage of the driver is $2.00 and of each horse $1.00.

To a fixed cost of 5½ cents per cubic yard add 2 cents per 100 feet of lead.

In a soil that does not heap up and push along in front of the scraper, the average load on long hauls will be reduced to ⅓ of a cubic yard. The rule then becomes:

To a fixed cost of 5½ cents per cubic yard add 3 cents for each 100 feet of lead.

Cost by Elevating Grader. An elevating grader will not work successfully in a soil where there are many boulders or roots to hinder the plow. The roadway must be wide enough to enable the machine to turn and to give sufficient room to the wagons which are brought up alongside the grader to be loaded. While the machine works satisfactorily in gravel roads and stiff clay, difficulty is sometimes experienced in a light, dry, sandy soil which will not readily turn a furrow. Although catalogues claim an average output of about 1,000 cubic yards per day, 500 cubic yards place measurement in an easy soil is a fair daily average. To handle an output of 500 yards per day satisfactorily will require six three-horse patent bottom dump wagons, each having a capacity of 1¼ cubic yards. The grader travels at about 150 feet per minute when drawn by a traction engine, and it takes about fifteen to twenty seconds to load a wagon of the above size. About fifteen seconds are lost waiting for an empty wagon to come up under the elevator after the loaded wagon has pulled away. There is some waste labor of the teams in following the grader, which may be fairly represented by adding 400 feet to the lead. Based on an output of 500 cubic yards per day of ten hours, the fixed charges are:

	Per cu. yd.
Lost time of teams	2.5 cents
10 horses on grader and 4 men	3.5 "
5 men on dump spreading	1.5 "
Interest, repairs and depreciation, $5.00 per day	1.0 "
	8.5 cents.

"To fixed cost of 8.5 cents add 0.6 cents per cubic yard per 100-foot lead."

An elevating grader is not an economical machine unless a trained crew and horses accustomed to the work are used. It also represents a big investment of money which few small

towns can afford and therefore is not a machine that can be generally recommended for ordinary road work when such work is to be carried out by the towns.

In all of the above data, unless otherwise stated, the wages of a laborer is \$1.50 and the cost of a horse is \$1.00 per day.

Cost with Road Scrapers. Baker states that by means of a road scraper drawn by four horses and with a driver and operator, it is possible to build a mile of prairie road 30 to 35 feet wide and with a crown of 6 inches after being compacted for \$30 to \$40 or 1⅔ to 2¼ cents per cubic yard.

Cost of Grading. The work of constructing an earth or sand-clay road is largely a matter of grading, and it is obvious that a variation in cost will result depending upon the kind of tools used and the amount and kind of material moved. To describe the cost as so many dollars per mile conveys no very accurate information to the engineer and makes it difficult to compare the cost of the work in one place with that in another. If unit prices are given this difficulty is obviated.

The costs of grading a number of gravel and sand-clay roads in several of the southern states during 1910, under the supervision of the U. S. Office of Public Roads, are given in the following table:

Soil	Cu. Yds. Moved	Cost Cu. Yd. Cents	Haul	Tools Used	Labor 10-hr. Day	Team 10-hr. Day
Sand top underlaid by clay.......	2400	15	200	Plow, picks, drag and wheel scrapers.	\$1.50	\$2.00
Sandy.............	3635	11.2	223	....	1.80[1]	3.60[1]
Subsoil, sand, loam clay and mixture.	3352	8.8	200	Road graders and 9 wheel scrapers; 8 drag scrapers.	1.60[2]	2.80[2]
Sand and clay......	3654	6.06	....	Road machine, drag scrapers; 5 dump wagons.	.50[3]	1.00
Black, waxy prairie subsoil..........	6407	38.1	....	Plows, graders......	1.50	3.00

[1] 9-hour day. [2] 8-hour day. [3] Convicts, mule team.

MAINTENANCE

EXTENT OF THE WORK. The principal work in maintaining an earth road is to keep the surface smooth and well crowned, consistent with the convenience of traffic, so as to shed water as rapidly as possible. If any depression forms in the surface, water settles in it and softens the road, with the result that a very small depression will work into a large and dangerous hole if not taken care of at once. In repairing holes in an earth

FIG. 65. An Earth Road Under Poor Maintenance.

road, they should be filled with the same kind of material that is used in the surface, for if a harder material than the surrounding earth is used, the surface will tend to wear unevenly at this point, due to the harder material offering more resistance to traffic. An earth road should have plenty of sunlight and air and hence the cutting of undergrowth at the sides is an excellent idea. Ditches and culverts should always be kept clean to give an easy outlet to the water.

Drags vs. Scrapers. A large part of the maintenance work, which consists of keeping the road in shape, can be done either by road scrapers and graders or by road drags. Different

types of these machines have been described in a previous part of this chapter. The road drag has been the salvation of the earth road. An earth road needs frequent care, and since drags can be obtained at an extremely low cost, it is possible for each resident along the road to own one. By having one drag to every 2 to 4 miles of road or less, and encouraging the people to use them frequently, the surface can be kept in a good condition all the time. Where road scrapers are employed, their number is generally limited so that it is only possible to use

FIG. 66. An Earth Road Under Good Maintenance.

them periodically a few times each year on the roads in a community. Frequently the surface may have become so badly worn that considerable work is necessary to get the road in good shape again. If enough scrapers were available so that repairs could be made at opportune times from the standpoint of the good of the road, the results obtained would probably be fully as good as those obtained by using road drags, but the cost of maintenance would be increased.

Road Drag Law. The Generally Assembly of the State of Illinois in 1908 passed a Road Drag Law authorizing the road commissioners in any township to have earth roads dragged at

all seasons of the year whenever it was deemed to be beneficial, and to contract with the adjoining land owners for this work at a rate of from 75 cents to $1.00 per mile, not less than 20 feet wide, for each time the road was dragged, the higher price to be paid for work done during the months of December, January, February, or March. The law also provides it to be unlawful to place loose earth, weeds, sods, or other vegetable matter on a road which has been dragged without the authority of the road officials; to place any material which will prevent the free flow of water; for any traffic to pass over a surface just dragged until same shall have partially dried out or have frozen, except in those instances where the road is not sufficiently wide to provide a safe by-pass or on roads wide enough so that the wheels will not make a rut nearer than 9 feet to the center of the dragged portion.

In order that all commissioners should follow the same practice, the following instructions were published:

"Roads properly dragged will dry out weeks earlier in the spring than a road not so maintained, and when dried out will be smooth and in excellent condition. Moreover, they will not rut up so readily during the winter. The ordinary country road can be well maintained if dragged at the proper time on an average of twice a month. The dragging will have to be more frequent during winter and spring than in the summer time.

"Unless the road is in the right condition, the work of dragging will be wasted. One thing to be insisted upon is that the work be done at the right moment. The right time is when the road is wet. The muddier it is the better the results. On a road that is in extremely bad condition where the mud is very deep, it is probable that the lap-plank drag can be worked to better advantage. In the summer time and early fall, dragging should be done while it is actually raining, for unless the rain is exceptionally heavy and long continued, the water will penetrate the dry roadbed so fast that the surface will be comparatively dry when the drag is used after the rain has stopped, with the result that the road surface will work up in crumbs. When this happens it is a sign the road is too dry. The nearer it is

possible to spread the mud over the road as a mortar, much in the same way a mason works mortar with a trowel, the greater the improvement produced. Under no conditions should a road be dragged when it is dry. This merely crumbles up the surface and makes a layer of the loose material which quickly becomes dust and is again turned into mud, which will hold water on the surface of the road; and this is exactly the condition that is to be prevented. Drag when the road is good and muddy. Don't drag when it is dry. Drag whenever possible at all seasons of the year. If a road is dragged immediately before a cold spell it will freeze in a smooth condition."

CHAPTER VIII

GRAVEL ROADS

Statistics gathered by the U. S. Office of Public Roads from road officials in various parts of the country show that there were approximately 103,000 miles of gravel roads in the United States in 1909, which is about double the amount improved with broken stone. There are many localities throughout the Middle West that are devoid of road-building stone, but are fortunate in having good gravel deposits.

The Gravel

Formation and Occurrence. The formation and occurrence of gravel deposits have been previously discussed in Chapter VI.

Requisites of Gravel. A gravel to make a good road-building material should be composed of stones that will not readily disintegrate under traffic; that vary from a large to a small size, the proportion of the different sizes being such that the voids will be a minimum; that contain enough binding material to fill the remaining voids and cement the whole mass together.

As a general rule a bank gravel is better than a stream gravel, since it contains more fine material which will act as a binder. River gravel contains more silica than a bank gravel of the same locality, since the clay is more readily washed out. A gravel which contains too much fine material may be improved by screening, while one which is lacking in binding material can be improved by adding some cementing material such as clay, shale, marl, loam, or stone screenings. An indication of the binding qualities of a gravel may be obtained by noticing the gravel in the bank. Usually if the bank faces are vertical, and

a pick is required to dislodge the gravel and large chunks may be broken out in which the smaller pebbles are firmly cemented together, the gravel will make a satisfactory road material.

The Binder. Frequently a mistake is made in selecting a gravel that will pack quickly, and as a result a gravel is used that contains an excess of clay, which is the most common form of binder that naturally occurs in gravels. An excess of 20 percent of clay in the mass will produce mud during a continued wet spell. Just enough clay to coat the pebbles without having any free lumps would be an ideal gravel. To remove an excess of clay, the gravel must be screened and sometimes washing will have to be resorted to. Iron oxide has been mentioned as one of the cementing materials found in some gravels, occurring as a slight coating on the pebbles. Gravels of this nature make an excellent road material and sometimes compact much more firmly in the road under traffic than in the original bed. The gravels from Paducah, Kentucky, and from Shark River deposits in New Jersey are examples of this type. Similar deposits, in which there is little or no clay present, are found where the cementing material is a lime or a combination of lime and iron ore. Enough small pebbles are sometimes present, which will crush up during the construction of the road or under the action of traffic and will furnish a binder that firmly cements the larger stones together. Loam and finely divided silica also compose the binding material in some deposits.

Specifications. The Michigan State Highway Department's specifications require that the gravel for the first course shall be good clean bank gravel, of which not less than 60 percent by weight shall be pebbles that will be retained on a screen of ⅛-inch mess and pass through a screen having 2½-inch holes. The gravel for the top course must be the same, except that no pebbles are allowed in this course too large to pass through a screen of 1½-inch holes and that not more than 20 percent of the mass shall be clay uniformly mixed and with no free lumps.

The 1912 specifications of the New York State Highway

Department require that a cementatious Hudson River gravel shall be used, equal in quality to Peekskill gravel; that the gravel for the bottom course shall consist of gravel varying in size from 3 inches to 1½ inches, with just a sufficient amount of fine material to fill the voids; that the gravel for the top course shall consist of gravel varying in size from 1½ inches to fine.

The specifications of Hennepin County, Minnesota, with regard to the gravel read as follows:

"Acceptable material will consist of 75 percent of clean coarse gravel varying in size from ⅛ inch to 1½ inches with 15 percent of clay and 10 percent of sand, the latter ingredients to be well mixed in mass.

"No sod, vegetable soil, or any foreign matter will be allowed, and care must be taken that strippings be not mixed with the gravel.

"A larger percentage of sand may be permitted on clay roads or a larger percentage of clay on sandy roads, to be approved by the engineer, if the excess be deposited uniformly on the subgrade."

Specifications for road gravel in 1912 to be furnished by the parks and parkways in the Borough of Brooklyn, New York, were as follows:

"The Hudson River road gravel required shall be what is known as 'double screened' and 'fine' gravel. It shall be free from all foreign substances and meet the following requirements.

"*Double Screened Gravel.* Percentage of wear not to exceed 5 percent.

"Percentage of voids not to exceed 45 percent.

"Cementation test by method U. S. Department of Agriculture to be not less than 25.

"Percentage retained on 1½-inch screen not to exceed 10 percent, nor be less than 5 percent.

"Percentage retained on ⅜-inch screen to be not less than 75 percent.

"*Fine Gravel.* Percentage of substances soluble in water not to exceed 5 percent.

"Percentage retained on 3/8-inch screen not to exceed 5 percent.

"Percentage in powder form not to exceed 5 percent."

Testing Gravel. Unless experience has proved that a gravel from a particular location is a satisfactory material, the gravel should be tested before being used. A variation may be found in the characteristics of gravels which come from pits in the same vicinity. It is just as important that gravels should be tested as it is to test broken stone.

Sampling. Samples of gravel should be taken with the sand or clay just as it occurs in the stream or gravel bank.

Mechanical Analysis. The proportions of the various sizes contained in any one sample can be ascertained by screening the sample through screens of different sizes, the proportions retained on or passing any screen being determined by weight.

The screens used in making mechanical analyses of gravel or stone are usually made with round holes having diameters varying from 2½ inches to 1/8 of an inch in size. The screens used in making mechanical analyses of sand, stone dust, and mixtures of sand and small gravel or small stone are made of wire with square holes. The sizes vary from ½ inch down to the finest screen which is used, or the one having 200 openings to the linear inch. The screens with square holes are designated as 2-mesh, 4-mesh, 200-mesh, etc., depending upon the number of openings per linear inch. The standard sizes of mesh screens for testing sand adopted by the American Society for Testing Materials are given in the following table:

Meshes per Linear Inch (= 2.54 cm.)	Diameter of Wire Inch	Diameter of Wire Mm.
200	0.00235	0.05969
100	0.0045	0.1143
80	0.00575	0.1460
50	0.009	0.22865
40	0.01025	0.26035
30	0.01375	0.34925
20	0.0165	0.4191
10	0.027	0.6858

The sample to be analyzed should be dry, and care should be taken when a small sample is to be selected from a mass of

material to obtain one which will be representative of the whole. This will generally involve thoroughly mixing the large mass before taking a sample from it. The size of sample to be screened will vary depending upon the size of the particles.

It is generally required in analyzing sands that the sieves shall be used starting with the smallest size and working up to the largest. No material, however, should be screened on the 200-mesh sieve without first removing all particles that are retained on the 10-mesh sieve. The weights of material passing the different sieves are obtained and recorded as percentages of the original sample. The sum of all of the percentages should add up to practically 100.

The sizes of screens used in analyzing a mixture of gravel and sand would probably include the 200, 80, 40, 10-mesh, ¼, ½, ¾, 1½, and 2½ inch. Any material which passes a 200-mesh sieve can be considered as powder.

Voids. The voids in a sample may be determined in several ways which will be described in detail in Chapter IX.

Quality of the Stone. The character of the stone may be determined by subjecting it to the standard abrasion and cementation tests in a manner similar to that for broken stone. These tests are described in Chapter IX.

Solubility in Water. The amount of material soluble in water is often desired. One method of making this test is to take a small sample that will represent an average of the large sample, mix this with water and boil it for about an hour, stirring the mixture frequently. Decant the liquid and filter. Evaporate the filtrate and weigh the residue which will be the amount soluble in water. The residue can be subdivided into its organic and inorganic compounds by weighing what remains after ignition.

Tables Nos. 3 and 4 are taken from Baker's "Roads and Pavements," and show the results of a physical and mineralogical analysis of gravels obtained from different parts of the country. All of these gravels are said to have made satisfactory road materials and the samples submitted for tests were selected with care by those familiar with the use of this material.

TABLE No. 3.

From Baker's "Roads and Pavements."

SIEVE ANALYSIS OF ROAD-BUILDING GRAVELS.

Ref No.	Size of Mesh	1. Urbana	2. Decatur	3. Lexington	4. Rockford	5. Peekskill	6. Buck Hill	7. Rock Hill	8. Shark River	9. Oaktown	10. Shaker Prairie	11. Paducah	12. Rosetta
1	Percent caught on 2-inch mesh.....	0.0	0.0	0.0	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	" " " " 1 " "	0.3	1.1	4.6	35.6	2.1	0.0	0.0	0.0	1.5	9.1	20.5	1.9
3	" " " " ½ " "	9.6	12.2	10.0	23.5	41.3	11.7	3.3	0.8	12.2	12.6	20.5	17.8
4	" " " " ¼ " "	13.0	10.5	8.7	7.4	25.5	11.0	13.4	12.7	18.6	9.1	8.8	11.0
5	" " " " 1/16 " "	41.1	14.8	20.2	9.1	17.8	8.4	25.1	33.2	47.5	21.3	13.8	22.3
6	" " " " 1/27 " "	12.1	3.9	15.3	3.2	2.2	20.4	14.0	7.4	8.9	9.3	5.2	20.0
7	" " " " 1/40 " "	3.9	7.8	15.9	2.7	1.8	8.2	7.2	5.5	3.5	9.3	1.9	10.5
8	" " passing 1/40 " "	16.2	40.0	21.0	8.7	8.4	20.2	16.3	20.0	6.1	18.8	21.8	10.4
9	" " in suspension " "	3.8	9.6	4.2	3.2	0.9	20.0	20.7	20.2	1.8	9.8	7.8	5.9
	Total..........................	100.0	100.0	99.9	99.4	100.0	99.9	100.0	99.6	100.1	99.3	99.7	99.8
	Percent voids in washed gravel......	25.5	30.5	27.3	29.6	30.5	26.3	34.0	28.2	25.6	24.2	24.5	25.3

TABLE No. 4.

From Baker's "Roads and Pavements."

MINERALOGICAL ANALYSIS OF ROAD-BUILDING GRAVELS.

Ref. No.	Mineral Constituents	1. Urbana	2. Decatur	3. Lexington	4. Rockford	5. Peekskill	6. Buck Hill	7. Rock Hill	8. Shark River	9. Oaktown	10. Shaker Prairie	11. Paducah	12. Rosetta
1	Limestone—pure carb of lime......	.....	21.9	.....	.....	.....	.....	.....	.....	18.9	28.6	.....	.....
2	ferruginous..................	65.0	8.1	21.0	.....	33.5	.....	.....	.....	.....	.....	.....	.....
3	with iron and silica............	.....	.....	.....	73.8	.....	.....	.....	.....	2.0	2.4	.....	.....
4	silicious....................	.....	.....	58.0	.....	.....	.....	.....	.....	.....	.....	.....	.....
5	Sandstone—ferruginous...........	.....	7.1	.....	.....	8.7	.....	.....	.....	0.4	.....	.....	.....
6	finely divided................	.....	.....	.....	.....	.....	.....	10.5	.....	0.5	3.7	.....	.....
7	coarse......................	.....	.....	.....	.....	.....	.....	3.8	.....	.....	.....	.....	.....
8	Metamorphic rock—iron, silica, mica	.....	.....	.....	.....	4.9	.....	.....	.....	2.0	.....	.....	.....
9	iron, sil., limestone............	.....	.....	.....	.....	.....	6.0	.....	.....	4.6	2.7	.....	.....
10	Conglomerate—iron..............	.....	.....	.....	1.7	.....	.....	.....	.....	.....	.....	.....	.....
11	limestone and quartz..........	.....	.....	.....	12.3	.....	.....	.....	.....	.....	.....	.....	.....
12	Crystalline rocks—acidic..........	4.6	10.1	1.4	.....	15.5	.....	.....	.....	12.1	11.4	.....	.....
13	basic..............	4.3	19.7	1.1	4.3	14.2	.....	.....	.....	13.2	13.2	.....	.....
14	Quartz, crystalline...............	22.2	23.3	13.7	4.6	22.1	73.9	64.3	78.8	38.8	27.8	.....	94.0
15	Chart, ferruginous...............	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	92.9	.....
16	Shale.........................	.....	.....	.....	.....	.....	.....	.....	.....	5.3	0.7	.....	.....
17	Clay..........................	3.8	9.6	4.2	3.2	0.9	20.0	20.7	20.2	1.8	9.8	6.8	5.8
	Total..................	99.9	99.8	99.4	99.9	99.8	99.9	99.3	99.0	99.6	100.3	99.7	99.8
	Percent of iron in the clay.........	7.6	9.1	9.1	9.4	.....	16.5	18.1	9.9	4.6	6.4	8.1	22.1

Construction

Preparation of Subgrade. The subgrade on which the gravel is to rest should receive just as careful attention as if it were being prepared for a broken stone surface. Thorough drainage and an adequate foundation for the road must be provided. The subgrade must be so prepared that it offers a firm surface on which the gravel top may be constructed. The transverse slope of the subgrade may or may not be parallel to the finished surface, since the gravel surface is frequently constructed thinner at the edges than at the center of the road.

The crown of a gravel road is made from ½ inch to 1 inch to the foot, ¾ of an inch to the foot being a common value.

There are two principal methods of construction which for the sake of distinction may be called the surface method and the trench method.

The Surface Method. The subgrade is brought to the proper shape by the use of a road grader or otherwise and firmly compacted. The gravel is brought to the road, dumped on the roadbed, and is smoothed out to the desired shape, the larger stone being raked over into the bottom of the road. A spike tooth harrow and a road drag scraper will be found extremely useful in this part of the work.

Width and Depth. The width and depth of the gravel surfacing necessary will depend upon the traffic conditions. A depth of from 8 to 15 inches at the center is quite common. As no shoulders are built in the subgrade at the sides to hold back the gravel, the edges will spread out during compaction so as to be of very little depth. More uniform results will be obtained if planks are laid on edge, at a distance apart a little less than the desired width of surface, and the gravel is filled in between these planks to the required depth. Only one or two lengths of plank are necessary since as the road is shaped up the planks can be moved ahead and the edges of the gravel will fall down, producing the desired thickness at the edges.

Compacting the Surface. The surface is then rolled, preferably with a grooved roller, until firmly compacted. A gravel

road should be compacted from the bottom up and a smooth face roller has a tendency to compact the uppermost part of the layer before the bottom is consolidated. If the traffic is not too heavy and it may be regulated so as to travel over all parts of the road, it will serve to compact the gravel much better than a smooth face roller. In order to take advantage of the rolling afforded by the traffic, the construction may proceed from the end of the road nearest the source of supply of the gravel. Since the narrow wheels are liable to rut the surface, a man should rake material into the ruts as they are formed and keep the whole surface in as smooth a condition as possible. When the gravel is deposited in one layer the lower part never gets the compaction that it should. It is good practice, therefore, to build the road in courses, compacting each course as it is laid. It is possible to make use of a poorer grade of gravel in the lower courses, or to take advantage of any waste products that would serve just as satisfactorily as gravel.

Frequently this method is abused by simply dumping the gravel on the surface, roughly smoothing it out with shovels, and leaving it for traffic to compact without giving it much of any further attention. Good results cannot be expected to be obtained by such a procedure.

Trench Method. In this method a trench is constructed in the subgrade of the same width as the gravel surfacing. The subgrade is otherwise prepared in the usual manner, so as to furnish a firm support for the gravel surfacing.

Formation of the Trench. The trench is obtained by building the portion of the roadbed prepared for the gravel below the sides an amount equal to the thickness of the gravel surface. On embankments the distance from the edge of the gravel surface to the edge of the slope of the bank should be at least 3 feet. This part of the roadbed is called the shoulder. In some cases when the gravel surface is deposited in more than one course, the depth of trench may be made equal to the thickness of the first course. After the first course has been laid, shoulders are constructed at either side of the same depth as the thickness of the remaining courses. The earth used for

the shoulders must be free from roots, stumps, and other vegetable matter. Material which will not compact properly should not be used. The final compaction of the shoulders cannot be accomplished until after the gravel surface has been completed. When finished the shoulders should have the same slope as the rest of the gravel surface so that a continuous slope is obtained from the center of the road to the outside edge of shoulder.

Constructing the Surface. In this method of construction the road is built up generally in two courses, although sometimes three courses are specified. It depends to a great extent upon the depth of the road desired.

Thickness of the Surface. The total thickness at the center is usually slightly more than the thickness at the shoulder. A depth of 8 inches at the center and 6 inches at the sides after rolling is quite common. The 1911 specification of the Maryland State Roads Commission calls for the construction of three courses for "Class A" roads and two courses for "Class B" roads. The thicknesses of the different courses after rolling are as follows:

	1st Course.	2nd Course.	3rd Course.
Class A	5 inches at center. 3 " on sides.	5 inches at center. 3 " on sides.	To be a light coating of sand, watered and rolled.
Class B	5 " uniformly.	3 " uniformly.	

The proper depths of the various courses during construction can be maintained by lines stretched between stakes, or by blocks placed on the surface of a thickness corresponding to the depth desired, the material being levelled off to the tops of the blocks.

Cross-sections. Typical cross-sections of a two-course and a three-course road are shown in Figs. 67 and 68, respectively, the former being a standard section of the Maine State Highway Department and the latter that of the Connecticut State Highway Department.

Sizes and Screening the Gravel. The size of the gravel used in the various courses has been given at the beginning of the chapter. Frequently it is impossible to find a gravel that con-

tains the exact proportions of sizes desired, and it is necessary to screen out some of the large or fine material. Screening may be accomplished by hand or by machine.

In Michigan the cost of screening gravel by hand through an ordinary mason's screen and loading the screened product into wagons was about 44 cents per cubic yard. By rigging a screen above one side of the wagon so that the gravel as ex-

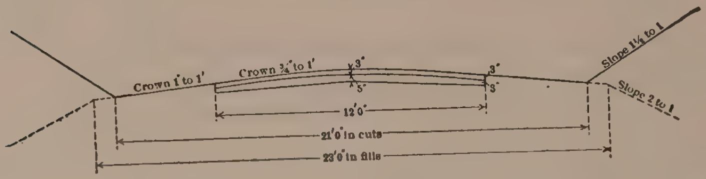


FIG. 67. Cross-section Gravel Road. Maine State Highway Department.

cavated could be thrown on it, the screened product dropping into the wagon, the cost of the screened product was lowered to about 22 cents per cubic yard.

In screening with machinery a bucket elevator can be erected so as to dump the gravel onto a chute screen or a rotary screen, the screened output falling into bins constructed high enough so that wagons can get underneath the pockets to be filled. The gravel to be screened can be brought to the boot of the elevator by wagon or by drag or wheel scraper. From 60 to 75 cubic yards per day can be screened by such an outfit and loaded into bins at a cost of from 20 to 25 cents per cubic yard.

Spreading the Gravel. The gravel for each course as it is brought to the road is either dumped to one side of the roadbed and shovelled into place or is shovelled directly from the wagon into place. The gravel may also be spread directly on the roadbed when certain types of approved bottom dump wagons are used. A dumping board should be used if it is necessary to dump the gravel on the roadbed from any other type of wagon than the ones just mentioned. The gravel is shaped up by using either shovels and rakes or by using a tooth harrow and

a road grader. When machines are used a considerable length of gravel should be placed before shaping with the machines, as otherwise their use would not be economical.

Compacting the Gravel. Each course after it has been shaped up is thoroughly compacted with a roller, both horse-drawn and power-driven rollers being employed. Some engineers do not favor the use of the heaviest types of rollers. Rolling for each course should be continued until a firm and even surface is obtained. If any depressions occur during the rolling, they should be filled up with the same size of material as is used in the remainder of that particular course. Sometimes difficulty which is experienced in getting a course to compact may be remedied by sprinkling with water or a light coating of sand or other fine material and rerolling. The top course is usually puddled with water in any event during the process of rolling. The water when mixed with the binder causes it to produce its cement-like qualities. Too much water, however, is detrimental, as it tends to wash out some of the finer binding material.

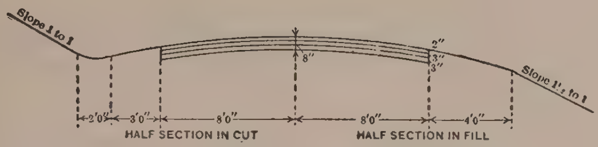


FIG. 68. Cross-section Gravel Road. Connecticut State Highway Department.

Rolling should always progress from the sides towards the center so as to maintain the crown of the road, and ultimately the rolling should extend over the whole width of road, including the shoulders. Gravel will compact to about 80 percent of its depth loose measure, hence if a finished thickness of 8 inches is desired, it will be necessary to use a total depth of 10 inches loose measure in the various courses.

Examples of Construction. John R. Rablin, M. Am. Soc. C.E., in speaking of the roads of the Metropolitan Park System of Boston, Massachusetts, before the Second International Road

Congress, said in part, "Gravel surfaced roads were constructed during the early stages of the development of the system and these proved to be much better suited to light traffic than macadam. They were better for horse driving, less affected by automobiles, and more easily repaired. During the last six or seven years this type of road has been built almost exclusively for these parkway drives. Where possible it has been the practice to obtain material composed of sharp angular stones with only sufficient clay to properly bind the stone. In some cases it has been necessary to use a clean, sandy gravel, and add clay binder during the process of construction, which method is generally not as satisfactory as when the material is in the proper proportions in its natural state. The surfacing material is 8 inches in depth and is laid in two 4-inch layers, and each layer is thoroughly compacted by the use of sectional grooved rollers drawn by horses. All stones larger than 1½ inches in diameter are screened out, or in cases where the material in the bank contains but little stone larger than this size, the larger stones are raked out after the gravel has been spread upon the road. The principal objection to this type of road is that at the season of the year when the frost is coming out, it is likely to rut if the amount of clay binder is at all excessive. This condition lasts only for a short time and the road surface is easily and cheaply smoothed out if the work is done immediately after the frost is out in the spring and before the surface becomes compacted in its rutted condition. To overcome this objection and still continue to have the gravel surfaced type of roads for the parkways, the writer has been for the last two years using a crushed stone base of about 4 inches in thickness with a 2½ to 3-inch layer of binding gravel on top. This method provides good drainage and a good base for the gravel surface."

Near San Diego, Cal., there are many places where the natural soil is a decomposed granite which is very similar to gravel. This material has been successfully used for road construction in that locality, and produces a hard, extremely smooth and lasting surface. The method of construction is to spread a 6-inch layer of the decomposed granite on the properly pre-

pared subgrade, compaction being obtained with a roller tamper, otherwise known as a sheep's foot roller. By means of this roller, compaction takes place from below and progresses to the surface. Rolling is continued until the feet of the roller cease to indent the surface. During the progress of rolling the surface is kept in shape and smoothed up by a road drag.

Cost Data. The following examples of the cost of construction of gravel roads are taken from the 1911 Report of the Director of the U. S. Office of Public Roads.

"Kalamazoo, Michigan. Gravel of a very good quality was obtained from a pit 2½ miles from the road and cost 10 cents per load at the pit. Various other items of cost were as follows: Stripping the pit, 0.1 cent per cubic yard; loading, 3.9 cents per cubic yard; hauling, 65.6 cents per cubic yard; spreading on the road, 0.9 cents per cubic yard; and harrowing, 0.2 cents per square yard. The road was rolled with a horse roller at a total cost of $22, which is 0.13 cents per square yard. The gravel was deposited in two courses; the first course, 7½ inches deep at the center and 4 inches deep at the edges, was compacted by rolling to 6 inches and 3 inches, respectively; and the second course, 3 inches deep at the center and 2 inches at the edges, was compacted by rolling to 2 inches and 1½ inches, respectively. The compacted surface was therefore 8 inches at the center and 4½ inches at the edges. The total amount of gravel used was 3,959 cubic yards. The work on this road was done by county prisoners at a cost of 40 cents per ten-hour day. Double teams cost $4.00 per day. The work comprised 17,613 square yards."

"Arlington, Texas. One thousand, nine hundred and seventy-four cubic yards of gravel were used, costing 95 cents per cubic yard at the railroad siding. Of this amount 212 cubic yards were used for concrete. Unloading the gravel from the train cost $536.50; hauling to the road, $860.25; spreading, $173.16; and patching, dressing, and sprinkling, $40.25. The gravel was deposited in three courses, 5 inches, 3 inches, and 8 inches, respectively, when loose, and was compacted by rolling

to 4 inches, 2 inches, and 6 inches, respectively, leaving a total finished gravel depth of 12 inches. The cost of rolling the gravel was $225.22. The crown was made 1 inch to the foot and the width surfaced was 14 feet for 3,400 and 12 feet for 3,528 feet, with shoulders making a 20-foot roadway. Additional items of expense on this road were as follows: Rolling the subgrade, $18.27; engineer's helper, $11.25; livery bill, $254.50; and miscellaneous supplies, tools, etc., $30.35. These figures of cost were based on a labor cost of $1.50 for a ten-hour day, foreman and team, each $3.00 per day. The work comprised 9,993 square yards."

"Center, Texas. Shaping the subgrade cost $16.10 and building the clay shoulders, $32.48. The gravel for this work was hauled by rail 145 miles and cost, on the siding, $1.00 per ton. A total of 398 cubic yards was delivered, one-half of which was unloaded by shovels over the side of the cars at a cost of 8 cents per ton and the other half was dumped from side dump-cars at a cost of 1 cent per ton. One hundred and ninety-eight tons of the gravel were screened by hand, through dash screens, yielding 50 percent of screened material, which cost 25 cents per ton. Loading this into wagons cost 3 cents per ton. The average haul to the road for the gravel was 800 feet and the cost was 17½ cents per ton. The gravel was deposited in two layers. The first course of unscreened material was 6 inches thick and was compacted by traffic. Four inches of the screened material, averaging in size from 1½ inches to ¼ of an inch, were then added, and the road was given a crown of ¾ of an inch to the foot. The cost of spreading the gravel by hand was 3.6 cents per ton. Other items of this road were as follows: General expenses, $10, and foreman, $65.55. The costs were based on a labor cost of $1.50 per 10-hour day and teams $3.50 per day. The work comprised 1,667 square yards."

The May, 1912, quotation for gravel delivered in 500 cubic yard lots alongside of the dock in New York City was 85 cents per cubic yard.

Prices for gravel roads constructed in place vary from $1.00

to $1.50 per cubic yard in New Hampshire, where a large amount of work has been done by contract.

Maintenance

It may take several months before a gravel surface is thoroughly compacted, no matter how well it may have been rolled during construction. During this period careful attention should be given to the road, and the ruts and hollows should be patched as soon as they are formed. In times of wet weather or of frost a gravel surface will be soft and rut very easily. As in the case of earth roads, the road drag is one of the best tools with which to maintain a gravel road. Where a road grader would unnecessarily disturb the surface, the road drag serves to simply smooth up the road, fill in the hollows and push just enough of the material towards the center to maintain the crown. Dragging will be more frequent for the first year after the road is completed than at any other time, and as is the case in all road dragging, the work should be done when the surface is in a moist and soft condition. As the road ages and becomes set, the road drags will not have any effect unless a prolonged period of rain has made the road very soft. There are many miles of gravel roads that have been maintained by means of a road drag at a cost of from $5.00 to $10.00 per year per mile.

All patching should be done when the road is in a wet condition, as the new material added will bond to the old and compact much better than when in a dry state. Moreover it is easier to locate the hollows since standing water will denote their presence. Great care should be taken not to get the patches too high as such a procedure is liable to create a new hollow just beyond the one patched. As near the same size and kind of material should be used in making the patches as was used in building the course. Constant patching and intelligent work with the road drag serves to keep a gravel road in good passable condition until it is entirely worn out and requires resurfacing.

When resurfacing is necessary the new gravel is added in a

manner similar to new construction. As in patch work, best results will be obtained by resurfacing when the old road is in a soft condition.

An essential part of the maintenance work is to keep ditches, drains and culverts clear to provide for the removal of the water which falls onto the road.

CHAPTER IX

BROKEN STONE ROADS

Broken stone roads are extensively built in all countries where stone is available. Although the water-bound type can no longer be built and maintained at a reasonable expense when subjected to certain types of traffic, there are conditions where it will continue to prove the most economical type of surfacing. The conclusion of the Second International Road Congress with regard to the water-bound type was as follows: "Macadam constructed according to the methods of Tresaguet and McAdam causes dust and mud, is expensive to maintain, and is only suitable in large cities for streets where the traffic is not very great or heavy." Some of the methods of constructing broken stone roads in combination with a bituminous material, up to a certain point, are practically the same as the construction of the water-bound type except for the addition of the bituminous material. The mileage of broken stone roads in the United States, according to statistics obtained by the U. S. Office of Public Roads, in 1909, was approximately 59,000.

Rocks

Rock Classification. Rocks may be separated into the following classes:

1. Igneous rocks, or those which have flowed upwards in a molten condition and cooled.

2. Aqueous rocks or those formed through the agency of water, including all sedimentary rocks.

3. Metamorphic rocks, or those rocks changed by dynamic or chemical agencies from their original condition which may have been anyone or a combination of the above classes.

Some rocks may be identified by the unaided eye by noting

No.	Rock varieties	Quartz	Orthoclase	Plagioclase	Augite	Hornblende	Calcite	Dolomite	Chlorite	Biotite	Muscovite
1	Granite	31.0[b]	45.8	7.3	....	....	0.2	....	0.9	3.8	3.4
2	Biotite-granite	28.0	36.1	12.2	1.4	0.5	0.1	....	0.4	10.5	0.4
3	Hornblende-granite	24.9	40.8	9.7	0.2	14.7	0.6	....	0.9	4.7	0.3
4	Augite-syenite	4.3	60.1	4.7	7.8	0.8	1.4	....	2.4	0.7	1.1
5	Diorite	6.2	5.6	33.0	0.1	34.0	1.1	....	1.9	2.3	....
6	Augite-diorite	1.1	22.0	29.6	14.8	13.3	0.3	....	4.4	4.5	....
7	Gabbro	0.7	....	42.7	26.3	11.0	0.3	....	1.4	3.5	....
8	Peridotite	....	....	....	16.0	0.6	....	....	....	....	....
9	Rhyolite	38.0	42.1	3.0	....	1.2	2.2	....	1.3	2.0	1.8
10	Andesite	9.7	....	45.7	8.6	1.9	7.3	....	6.8	....	1.1
11	Fresh basalt	....	....	36.1	45.0	0.1	0.1	....	0.2	0.1	....
12	Altered basalt	....	....	28.6	24.9	....	3.4	....	10.2	....	....
13	Fresh diabase	....	....	48.8	44.4	....	0.1	....	0.9	0.4	(a)
14	Altered diabase	0.6	....	37.4	20.2	7.5	1.0	....	13.0	1.3	....
15	Limestone	6.4	....	....	....	....	82.3	6.0	....	....	....
16	Dolomite	8.6	0.4	....	....	....	7.5	78.6	....	....	....
17	Sandstone	71.2	3.1	0.3	....	....	1.1	....	0.8	0.3	4.4
18	Feldspathic sandstone	42.1	24.3	0.2	....	....	0.4	....	3.7	0.9	1.8
19	Calcareous sandstone	39.6	17.3	0.3	....	....	35.3	....	3.8	0.2	0.3
20	Chert	94.2	0.1	....	....	....	0.9	....	0.1	(a)	0.2
21	Granite-gneiss	37.2	41.1	2.5	....	0.4	0.3	....	1.9	4.7	4.9
22	Hornblende-gneiss	11.1	18.4	1.0	....	53.4	....	....	....	1.9	3.5
23	Biotite-gneiss	40.9	33.2	0.9	....	0.1	0.3	....	1.0	12.9	1.5
24	Mica-schist	39.3	14.8	1.4	....	....	2.1	....	1.3	14.6	19.2
25	Biotite-schist	27.3	13.7	3.4	0.4	10.3	....	....	(a)	38.7	0.2
26	Chlorite-schist	19.9	10.1	3.3	....	....	1.2	....	36.3	0.2	4.6
27	Hornblende-schist	11.3	4.7	6.9	1.0	62.5	0.5	....	0.7	0.5	0.4
28	Amphibolite	3.1	2.9	6.5	....	71.0	0.2	....	....	1.1	....
29	Slate	25.9	....	0.1	....	....	2.4	....	....	0.9	63.8
30	Quartzite	86.2	1.9	0.2	....	0.8	1.3	....	0.8	3.7	2.2
31	Feldspathic quartzite	46.3	33.7	1.2	....	....	2.1	....	5.7	1.1	4.4
32	Pyroxene quartzite	36.0	3.6	25.1	22.2	....	....	....	....	....	....
33	Eclogite	5.0	....	28.8	14.5	1.8	1.2	....	0.8	4.5	....
34	Epidosite	16.8	1.8	....	....	13.6	....	....	....	....	....

From Bulletin No. 31. Office of Public Roads. U. S. Dept. of Agriculture.

TABLE No. 5.—*Average mineral composition and physical properties of rocks for road*

Mineral composition, expressed in percentages																
Epidote	Magnetite	Limonite	Microcline	Rock glass	Garnet	Olivine	Pyrite	Hematite	Serpentine	Hypersthene	Opal	Titanite	Apatite	Scolecite	Natrolite	Zircon
0.9	0.6	0.3	**3.7**	....	0.1	....	0.1	0.2	....	....	....	0.1	0.1	....	....	0.1
1.7	0.8	....	**4.4**	....	0.1	....	....	0.3	....	....	....	0.5	0.2	....	....	0.1
0.9	0.6	0.1	0.2	....	....	....	(a)	....	....	....	....	0.3	0.1	....	....	(a)
3.0	2.1	0.1	**9.9**	....	....	....	0.1	....	....	....	....	0.1	0.1	....	....	0.1
3.7	3.1	0.1	....	....	....	....	0.6	....	....	....	....	0.5	0.5	....	....	0.1
0.1	**5.2**	....	....	....	....	....	0.1	....	....	....	....	0.2	0.8	....	....	0.1
0.6	2.3	0.1	....	....	....	1.1	....	....	0.4	1.6	....	....	....	0.1	....	....
....	**30.6**	0.3	....	....	....	**5.0**	....	....	**27.5**	**20.0**	....	....	....	....	....	....
2.7	1.8	0.7	0.1	0.6	....	....	0.2	0.7	....	....	....	....	(a)	....	....	(a)
8.5	3.2	1.8	....	3.0	....	....	....	....	....	....	2.2	....	0.2	....	....	....
....	4.0	0.1	....	**8.2**	....	4.3	....	....	1.8	....	....	....	....	....	....	....
5.1	2.9	0.2	....	**10.3**	....	0.5	....	....	2.9	....	....	....	....	....	0.7	....
....	4.2	....	....	....	....	0.8	(a)	....	0.3	....	....	....	(a)	....	....	....
4.4	6.1	0.3	....	....	....	1.6	0.2	....	0.9	....	....	0.2	0.2	0.9	0.5	....
....	....	1.7	....	....	....	....	3.4	0.2	....	....	....	....	....	....	....	....
....	....	1.7	....	....	....	....	1.2	1.1	....	....	....	....	....	....	....	....
(a)	0.5	6.1	....	....	0.6	....	0.3	6.2	....	....	3.4	....	(a)	....	....	0.1
0.9	0.8	4.2	....	....	....	....	....	....	....	....	....	(a)	....	....	....	0.1
....	0.5	2.4	....	....	0.1	....	0.1	....	....	....	....	....	....	....	....	0.1
....	0.1	2.0	....	....	0.7	....	0.1	0.2	....	....	0.7	....	....	....	....	....
1.6	0.7	0.2	2.9	....	0.1	....	0.1	....	....	....	....	0.1	0.1	....	....	0.1
2.3	2.4	0.2	3.3	....	0.3	....	0.6	....	....	....	....	0.3	0.7	....	....	0.3
1.5	1.7	0.2	2.9	....	0.7	....	0.1	....	....	....	....	0.3	1.2	....	....	0.1
4.5	1.4	(a)	....	....	0.3	....	0.4	(a)	....	....	....	....	0.4	....	....	0.1
1.0	1.3	....	0.2	....	2.0	....	1.4	....	....	....	....	....	(a)	....	....	0.1
0.4	2.6	0.4	....	....	....	....	0.5	....	....	....	....	0.5	....	....	....	....
4.7	2.1	0.4	0.4	....	2.4	....	0.3	....	....	....	....	0.6	0.1	0.1	....	(a)
0.7	1.9	0.2	....	....	0.1	....	....	....	....	1.4	....	0.8	0.1	....	....	....
2.4	2.1	2.1	....	....	....	....	0.2	....	....	....	....	....	....	....	....	0.1
1.0	0.3	1.0	....	....	0.1	....	....	0.3	....	....	....	....	0.1	....	....	0.1
2.3	0.4	1.5	....	....	....	....	....	0.5	....	....	....	0.2	....	....	....	(a)
....	4.0	....	....	....	1.9	....	0.3	....	....	6.7	....	....	0.2	....	....	....
....	4.7	....	....	....	38.4	....	0.1	....	....	....	....	....	0.2	....	....	....
4.9	1.9	0.9	....	....	....	....	....	....	....	....	....	....	....	....	....	0.1

(a) Trace. *b* Figures in bold type indicate the essential mine

Nephelite	Fluorite	Tourmaline	Rutile	Sillimanite	Topaz	Physical properties: Percent wear	Toughness	Hardness	Cementing value	Specific gravity.	Rock varieties	No.
...	(a)	....	....	....	....	3.5	15	18.1	20	2.65	..............Granite	1
...	(a)	....	....	....	(a)	4.4	10	16.8	17	2.64	.......Biotite-granite	2
...	....	....	....	....	....	2.6	21	18.3	30	2.76	...Hornblende-granite	3
0.2	....	....	....	....	....	2.6	10	18.4	24	2.80	.......Augite-syenite	4
...	....	....	....	....	....	2.9	21	18.1	41	2.90	..............Diorite	5
...	....	....	....	....	....	2.8	19	17.7	55	2.98	........Augite-diorite	6
...	....	....	....	....	....	2.8	16	17.9	29	3.00	..............Gabbro	7
...	....	....	....	....	....	4.0	12	15.2	28	3.40	............Peridotite	8
...	....	....	....	....	....	3.7	20	17.8	48	2.60	.............Rhyolite	9
...	....	....	....	....	....	4.7	11	13.7	189	2.50	.............Andesite	10
...	....	....	....	....	....	3.3	23	17.1	111	2.90	.........Fresh basalt	11
..	....	....	....	....	....	5.3	17	15.6	239	2.75	........Altered basalt	12
..	....	....	....	....	....	2.0	30	18.2	49	3.00	........Fresh diabase	13
..	....	....	....	....	....	2.5	24	17.5	156	2.95	......Altered diabase	14
..	....	....	....	....	....	5.6	10	12.7	60	2.70	...........Limestone	15
..	....	....	....	....	....	5.7	10	14.8	42	2.70	............Dolomite	16
..	....	(a)	(a)	....	....	6.9	26	17.4	90	2.55	...........Sandstone	17
..	....	(a)	....	....	....	3.3	17	15.3	119	2.70	.Feldspathic sandstone	18
..	....	....	....	....	....	7.4	15	8.3	60	2.66	..Calcareous sandstone	19
..	....	(a)	....	....	....	10.8	15	19.4	27	2.50	...............Chert	20
..	....	....	....	(a)	....	3.8	12	17.7	26	2.68	........Granite-gneiss	21
..	....	....	....	....	....	3.7	10	17.1	30	3.02	....Hornblende-gneiss	22
..	....	....	....	....	....	3.2	19	17.5	41	2.76	........Biotite-gneiss	23
..	....	....	....	....	....	4.4	10	17.3	30	2.80	..........Mica-schist	24
..	....	....	....	....	....	4.0	....	....	16	2.70	.........Biotite-schist	25
..	....	....	....	....	....	4.2	....	....	24	2.90	.......Chlorite-schist	26
..	....	....	....	....	....	3.7	21	16.5	53	3.00	....Hornblende-schist	27
..	....	....	....	....	....	2.9	10	19.0	29	3.00	.........Amphibolite	28
..	....	(a)	....	....	....	4.7	12	11.5	102	2.80	................Slate	29
..	....	(a)	....	....	....	2.9	19	18.4	17	2.70	............Quartzite	30
..	....	(a)	(a)	....	....	3.2	17	18.3	21	2.70	..Feldspathic quartzite	31
..	....	....	....	....	....	2.3	27	18.6	17	3.00	....Pyroxene quartzite	32
..	....	....	....	....	....	2.4	31	17.4	21	3.30	.............Eclogite	33
..	....	....	....	....	....	3.6	16	16.0	47	3.03	............Epidosite	34

haracteristic of the rock variety.

CHAPTER IX

BROKEN STONE ROADS

Broken stone roads are extensively built in all countries where stone is available. Although the water-bound type can no longer be built and maintained at a reasonable expense when subjected to certain types of traffic, there are conditions where it will continue to prove the most economical type of surfacing. The conclusion of the Second International Road Congress with regard to the water-bound type was as follows: "Macadam constructed according to the methods of Tresaguet and McAdam causes dust and mud, is expensive to maintain, and is only suitable in large cities for streets where the traffic is not very great or heavy." Some of the methods of constructing broken stone roads in combination with a bituminous material, up to a certain point, are practically the same as the construction of the water-bound type except for the addition of the bituminous material. The mileage of broken stone roads in the United States, according to statistics obtained by the U. S. Office of Public Roads, in 1909, was approximately 59,000.

Rocks

Rock Classification. Rocks may be separated into the following classes:

1. Igneous rocks, or those which have flowed upwards in a molten condition and cooled.

2. Aqueous rocks or those formed through the agency of water, including all sedimentary rocks.

3. Metamorphic rocks, or those rocks changed by dynamic or chemical agencies from their original condition which may have been anyone or a combination of the above classes.

Some rocks may be identified by the unaided eye by noting

the color, the structure, the weight and the hardness. By preparing microscopic slides and examining them under a petrographical microscope, it is possible to identify those which cannot be determined by the eye alone.

Definitions. A few terms used in describing the structure of rocks will be given.

Amorphous, wholly without crystalline structure.

Cellular, due to the weathering out of some constituent.

Clastic or fragmental, a reconsolidation without crystallization of rocks previously broken down.

Colloidal, a jelly or glue-like structure.

Compact, granular, but too fine to be determined without microscope.

Crystalline, such as ordinary granite.

Foliated or schistose, a tendency to split along line of stratification.

Granitoid, a descriptive term for igneous rocks composed of recognizable minerals of approximately the same size.

Granular, made up of distinct grains.

Holocrystalline, made up wholly of a crystalline structure.

Laminated, a banded structure common in sedimentary rocks.

Massive, igneous rocks that show no stratification

Plutonic, rocks which never reached the surface when cooling.

Porphyritic, a compact mass throughout which are attached larger crystals.

Slaggy, a ropy structure assumed on cooling.

Stratified, built up in parallel layers.

Vitreous or glassy, only found in igneous rocks.

Volcanic, rocks which were erupted in a molten condition and cooled on the surface.

Mineral Constituents. A rock is a mineral or combination of minerals. There are a few rocks which are composed entirely of one mineral, but the majority are made up of a combination of two or more different minerals. Among the most important chemical compounds occurring in rocks are silicates, oxides, carbonates, sulphates, chlorides, phosphates, sulphides, and

one native element graphite. Sedimentary rocks are spoken of as calcareous, siliceous, ferrugineous or argillaceous according as lime, silica, iron oxides or clayey matter are predominant. Eruptive rocks are spoken of as acidic or basic, the former being those showing more than 65 percent silica, and the latter those which show less than 55 percent, but are rich in iron, lime and magnesian constituents. Among the more common minerals found in rocks are the following: quartz, feldspar, orthoclase, plagioclase, amphibole, pyroxene, mica, olivine, epidote, calcite, dolomite, magnetite, hematite, limonite, pyrite, chlorite, serpentine, galconite and zeolites.

The mineral constituents which make up a rock can be determined by means of the crystalline formation, by chemical analysis, by blow-pipe analysis, and microscopical examination.

Table No. 5* gives the mineral constituents and the physical characteristics of the principal road-making rocks. Group 1 to 8 comprises the plutonic igneous rocks, 9 to 14 the volcanic igneous, 15 to 20 the sedimentary, and 21 to 34 the metamorphic rocks or crystalline schists.

Trap. Andesites are generally gray, greenish or reddish in color. Their structure when examined under a microscope is found to vary from a glassy to a holocrystalline. Their principal constituent is plagioclase. Basalts are a homogeneous rock, generally of a dark gray or black color, although red and brown colors are also common. In structure they vary from a glassy to holocrystalline. Diabases are holocrystalline in structure and vary in color from greenish to a dark gray or nearly black. Peridotite is greenish or black in color with a variable structure that may be either crystalline, granular or porphyritic.

Diorite. The diorites are a granitoid rock whose essential constituents are plagioclase, feldspar, either labradorite or oligoclase, and hornblende or black mica. They are green, dark gray or black in color. Gabbros are crystalline granular in structure, the prevailing color being black and sometimes

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* See "Rocks for Road Making," by E. C. E. Lord. U. S. Office of Public Roads Bulletin, No. 31.

greenish. As is seen from the table its main constituents are plagioclase, augite and hornblende, quartz being rarely present.

Granite. The essential constituents of granite are quartz, feldspar and plagioclase, combined usually with mica, hornblende and pyroxene. It is holocrystalline granular in structure. It may be gray, green, yellow, or red in color, the lighter colors being due to the feldspar and the darker colors due to the mica and hornblende. Quartz porphyries have the same constituents as granite but are porphyritic in structure, having quartz crystals scattered through a ground mass which may be red, gray, yellow, green, black or white in color.

Syenite. Syenites are the same in composition as granites except that there is no quartz. In structure and color they are the same as granite.

Gneiss. Gneisses are of a holocrystalline granular structure arranged in parallel bands. At one time this foliated structure was supposed to have been due to original stratification. The theory now, however, is that it is due in a large part to pressure. Gneisses are practically the same in composition and color as the granites, the principal difference being the structure. The different varieties, as in granites, are called by the name of the predominating mineral.

Limestone. Limestones are extremely variable in both color and structure. All shades from white through a gray to a black are common and sometimes even red and yellow are found. They are stratified in structure and vary from a soft variety to a rock with a dense structure that breaks with a distinct fracture. Chats is a term used in the West to denote the tailings of lead mines. It is a dolomite limestone.

Sandstone. Sandstones, like limestones, are variable both as to color and structure. In color they are red, brown, green and yellow. Pudding stone or conglomerate is a coarse sandstone. Breccia is similar to conglomerate except the stones are more angular. Sandstones consisting almost entirely of quartz are sometimes called grit. Flints, so-called in Great Britain, are found in the upper layers of chalk pits or in gravel deposits near

the chalk areas. They are made up of colloidal and crystalline silica. Chert is a variety of quartz of a flinty structure. Quartzites are a metamorphosed sandstone, brown, red or green in color.

Schist. The schists differ from the gneisses principally in the lack of feldspar. Amphibolite has hornblende for its principal constituent and is a tough and often a massive rock.

Slate. Slate is an indurated or hardened clay, generally of a dark color with a foliated structure.

Fieldstone. Fieldstones are boulders which have been carried along by the glacier and are found mainly in those districts which were covered by this great ice sheet. They are composed of a variety of different kinds of rocks.

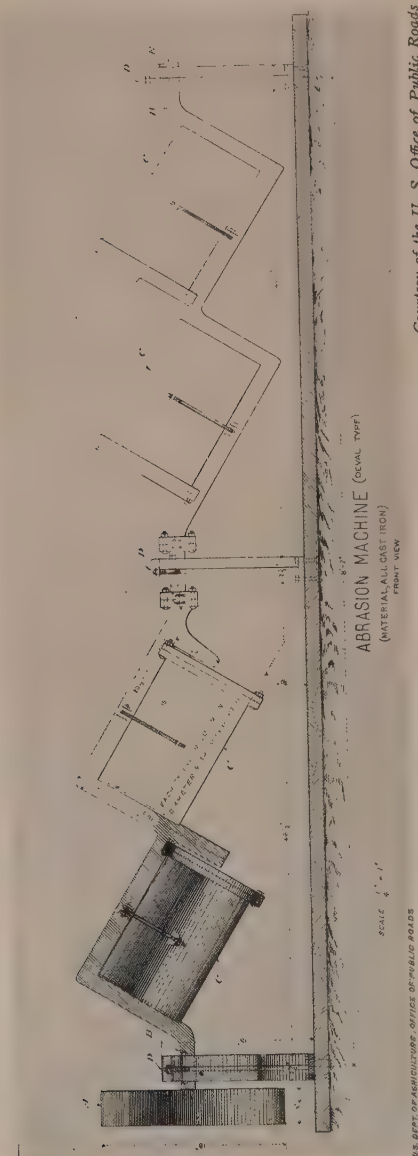
Properties Rock Should Possess. A rock should possess the following characteristics in order to make a first-class stone for water-bound broken stone roads: It should be tough so as to resist the shocks from the traffic; it should have a good resistance to the wear caused by the grinding action of the wheels; it should possess good cementing power; it should break with a clean angular fracture. The various rocks used for road building purposes are popularly known as trap, granite, limestone, sandstone and fieldstones.

Trap. Trap rocks are extremely hard and tough and their excellent wearing and binding qualities have caused their widespread use throughout those sections of the country where they are found. When used in the construction of broken stone roads subjected to a light traffic, however, the wear on the stones will not usually be sufficient to make enough binder to hold the stones together. To prevent the surface from ravelling, more binder or a bituminous material must be applied.

Granite. Granites which have a close, even and granular structure make good road material for broken stone roads which take a light traffic. If of a coarse structure they are not so desirable, but might be used in the foundation courses.

Limestone. Limestones possess excellent binding qualities but are generally neither hard nor tough and therefore are more suitable for roads having a light traffic.

Sandstone. Sandstones, due to the fact that they are easily broken up under the action of traffic and are usually lacking in binding qualities, are generally not considered as good road material except for the foundation courses. Quartzites, which are a metamorphosed sandstone, give better results than sandstones as they are harder.



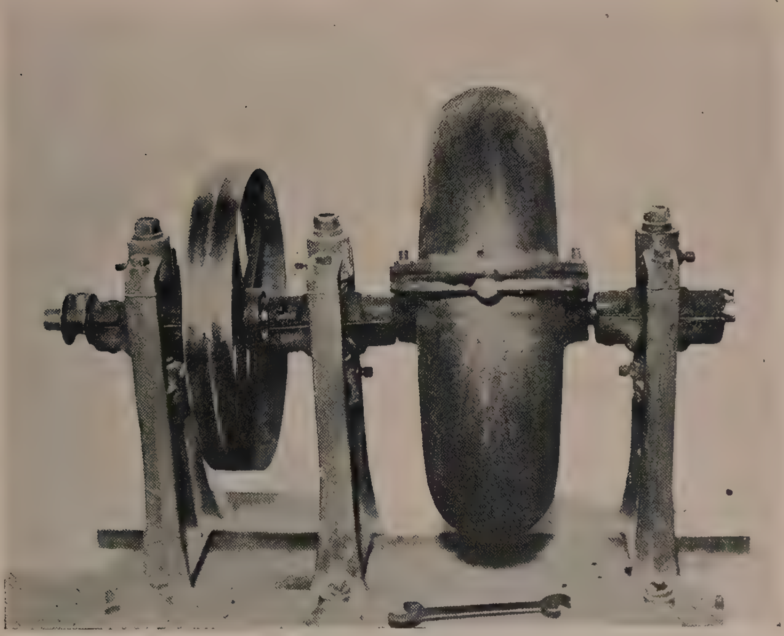
Courtesy of the U. S. Office of Public Roads

Fig. 69. Deval Machine.

Fieldstones. Fieldstones frequently make a satisfactory material for light traffic roads. They are extremely variable in composition as would be expected considering the nature of their source.

Testing the Rock. In order to ascertain the value of any rock as a material suitable for road building there are several tests that have been developed which give some indication as to what may be expected of a rock when used in the road. The tests are made to determine certain specific characteristics, and although the results of the tests do not always agree with the result obtained in construction, still they

are a great aid in comparing the respective qualities of different stones. There are many variable conditions to which a road is subjected, and since it is difficult to duplicate these conditions by any accelerated mechanical test, the best knowledge in regard to the worth of any rock will be obtained from observations of its wear in actual service, in other words by constructing experi-

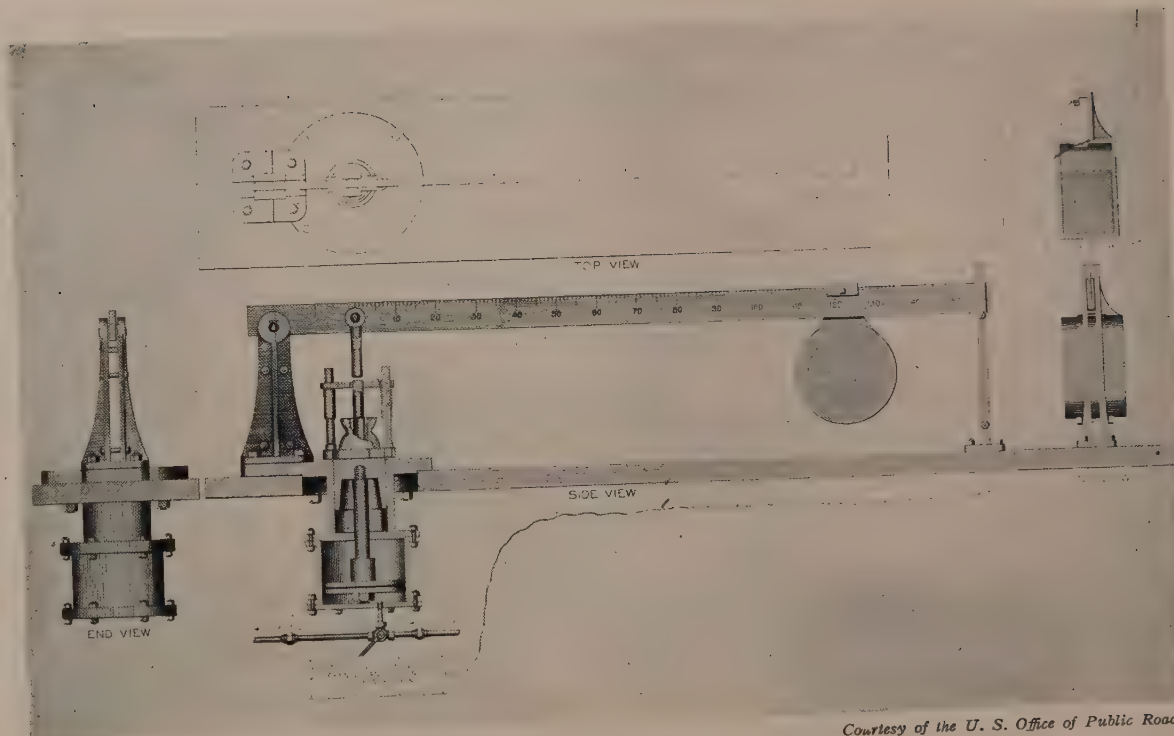


Courtesy of the U. S. Office of Public Roads.

FIG. 70. Ball Mill.

mental stretches with different kinds of stone and seeing how they work out. The principal mechanical tests which are made are abrasion, cementing value, toughness, hardness, absorption and specific gravity. The relative values of the results of tests as listed in the following descriptions are those proposed by the U. S. Office of Public Roads.

Abrasion. This test is made by means of the Deval machine. This machine, Fig. 69, consists of a series of cylinders or tubs mounted on a shaft with the long axis of the tubs making an



Courtesy of the U. S. Office of Public Roads.

FIG. 71. Briquette Molding Machine.

angle of 30 degrees with the horizontal. Mounting the cylinders in this manner causes the rock to be thrown from one end of the cylinder to the other as the machine revolves. The American Society for Testing Materials requires in making this test that "the rock to be tested shall be broken in as nearly uniform pieces in size as possible, and as nearly 50 pieces as possible shall constitute a test sample. The total weight of rock in a test shall be within 10 grams of 5 kilograms. All test pieces shall be washed and thoroughly dried before weighing. Ten thousand revolutions at the rate of between 30 and 33 to the minute must constitute a test. Only the percentage of material worn off which will pass through a 0.16 centimeter (1-16 inch) mesh sieve shall be considered in determining the amount of wear. This may be expressed either as the percent of the 5 kilograms used in the test, or the French coefficient, which is in more general use, may be given; that is, coefficient of wear $20 \times \frac{20}{W} = \frac{400}{W}$. W is the weight in grams of the detritus under 0.16 centimeter (1-16 inch) in size per kilogram of rock used." In determining the material under 1/16 inch in size, the charge after completing the test is screened through a 1/16-inch mesh sieve. The material retained on the sieve is then thoroughly washed, dried, cooled and weighed. This weight subtracted from the original weight gives the amount of loss under 1/16 inch in size. A coefficient of wear of 8 is low, 8 to 13 medium, 14 to 20 high, and above 20 very high.

Cementing Value. The test for cementing value as made by the U. S. Office of Public Roads is as follows: Five hundred grams of the rock to be tested, broken to pass a ½-inch mesh sieve, are placed in a ball mill together with 90 cubic centimeters of water and 2 steel shot weighing 20 pounds. The ball mill, as shown in Fig. 70, consists of a hollow, circular shell mounted on a shaft. The ball mill and its charge are revolved for 2½ hours at a rate of 2,000 revolutions per hour. The addition of the water in the ball mill makes the charge into an extremely stiff dough. This dough is removed and 25 grams are placed in a metal die, 25 millimeters in diameter and subjected to a pressure

Courtesy of the U. S. Office of Public Roads.

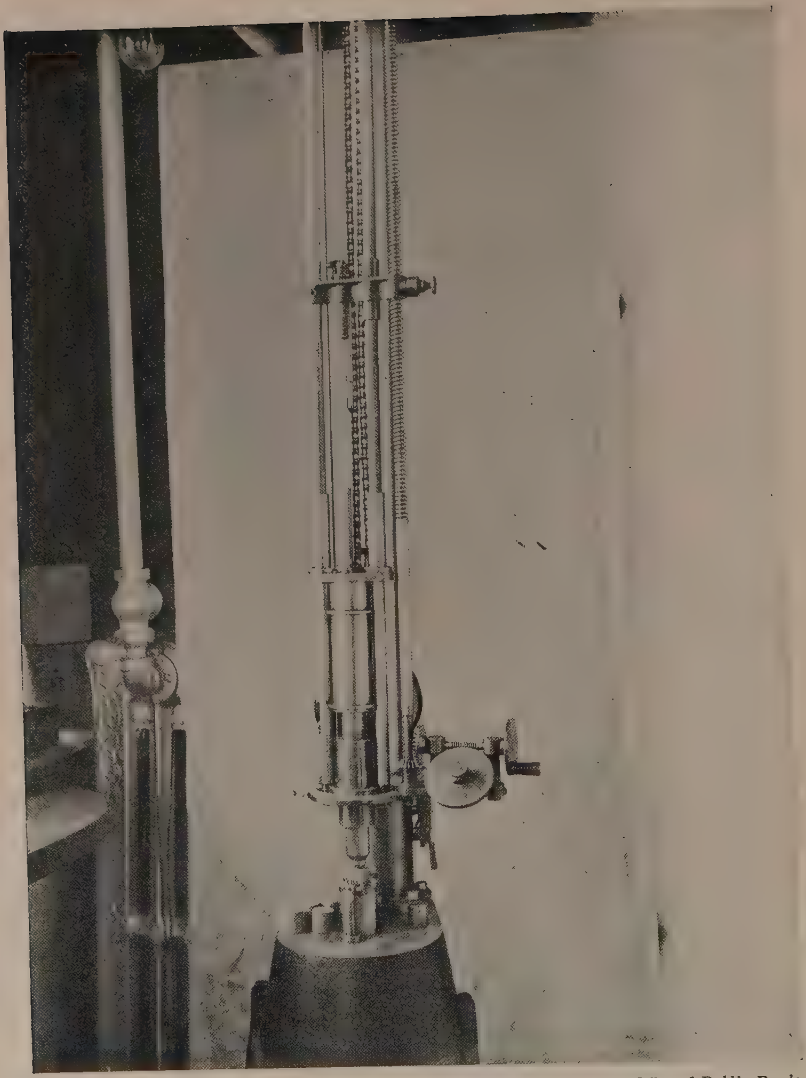
FIG. 72. Impact Machine for Determining Cementing Value.

of 132 kilos per square centimeter for an instant in a hydraulic press, see Fig. 71. The cylindrical briquette resulting is measured to see if it is exactly 25 millimeters in height. If not, more dough is weighed out and an amount is subtracted or added to the 25 grams so that the briquette after compression will be exactly 25 millimeters in height. One or two trials will determine the proper amount. Five briquettes are made and allowed to dry in the air for a period of 20 hours, after which they are heated in a hot-air oven for 4 hours at a temperature of 200 degrees Fahrenheit and then cooled in a desiccator for 20 minutes. The briquettes are now ready for testing. The machine used for testing the briquettes is shown in Fig. 72. In this machine a 1-kilogram hammer is raised by a revolving cam to a height of 1 centimeter. The hammer falls on a plunger and transmits the energy of its blow through the plunger to the test piece. The instrument is provided with a self recording apparatus which registers each blow struck until the test piece fails. Until the test piece fails there is a vertical movement imparted to the pointer which causes it to mark a vertical line on the silicated paper wrapped around the drum. In order to securely fasten the test piece to the anvil, a drop of shellac is placed on the bottom of the briquette when it is placed in the machine. The average of the number of blows on 5 briquettes is taken as a result of the test. A result of 10 is low, 10 to 25 fair, 26 to 75 good, 76 to 100 very good, over 100 excellent.

Toughness. The test for toughness is made in the machine shown in Fig. 73. As adopted by the American Society for Testing Materials the test is made as follows:

"1. Test pieces may be either cylinders or cubes, 25 millimeters in diameter, and 25 millimeters in height, cut perpendicular to the cleavage of the rock. Cylinders are recommended as they are cheaper and more easily made.

"2. The testing machine shall consist of an anvil of 50 kilos weight, placed on a concrete foundation. The hammer shall be of 2 kilos weight, and dropped upon an intervening plunger of 1 kilo weight, which rests on the test piece. The lower or bearing surface of this plunger shall be of spherical shape



Courtesy of the U. S. Office of Public Roads.

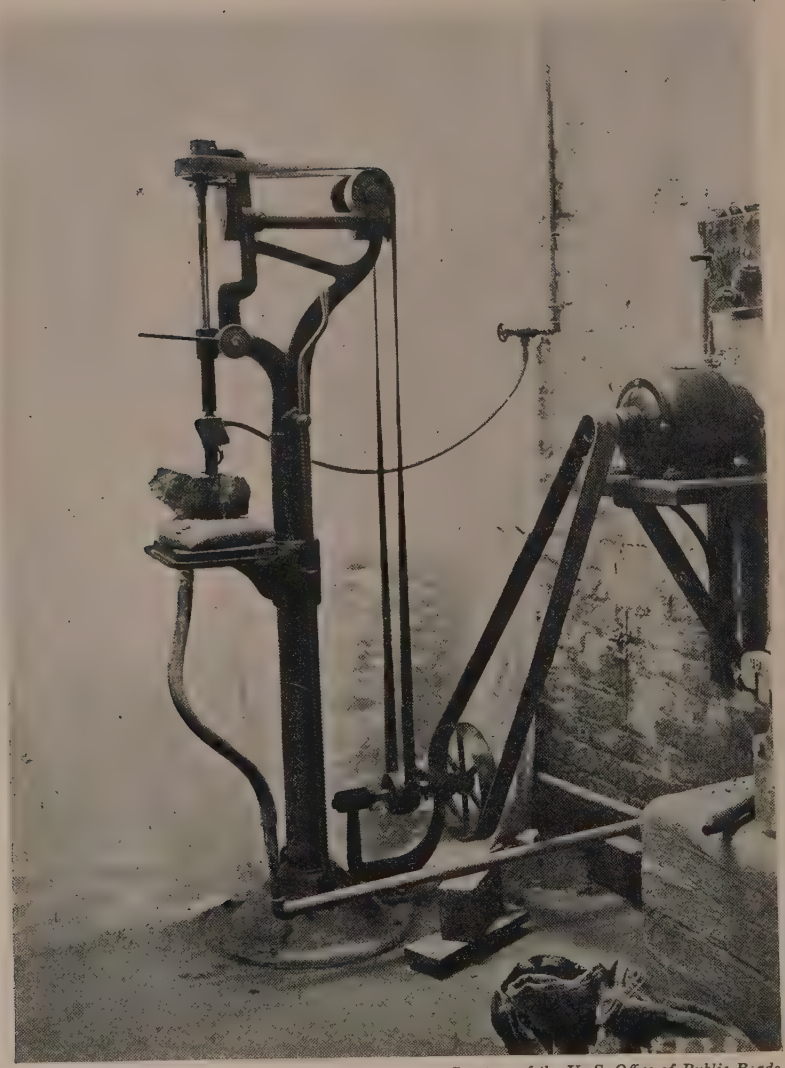
FIG. 73. Page Impact Machine for Determining Toughness.

having a radius of 1 centimeter. This plunger shall be made of hardened steel, and pressed firmly upon the test piece by suitable springs. The test piece shall be adjusted so that the center of its upper surface is tangent to the spherical end of the plunger.

"3. The test shall consist of a 1-centimeter fall of the hammer for the first blow, and an increased fall of 1 centimeter for each succeeding blow until failure of the test piece occurs. The number of blows necessary to destroy the test piece is used to represent the toughness, or the centimeter-grams of energy applied may be used." A result of 13 is low, 13 to 19 medium, and above 19 high.

Hardness. The test for hardness is made by means of a Dorry machine, Fig. 76, which consists of a revolving steel disc on which is fed a standard quartz sand, between 30 and 40 mesh, through the funnels at a uniform rate. A rock core 25 millimeters is cut from the rock and its faces ground off level by means of the core drill, diamond saw and grinding lap, shown in Figs. 74 and 75. Two cores are used in each test and are placed in the dies, which are supported by the guide cylinders shown near the funnels. The dies with rock cores should weigh 1,250 grams each and are so arranged that their entire weight is borne by the test piece. The test piece is first weighed and is then ground on one face for 1,000 revolutions, after which it is reversed and the other face ground for the same number of revolutions. The loss in weight of the specimen is determined at the end of each 1,000 revolutions, and the average loss in weight is used in stating the hardness of the rock, which is expressed by the formula, Hardness $= 20 - \frac{1}{3} W$, where $W =$ loss in grams per 1,000 revolutions. Rocks having a coefficient of hardness below 14 are called soft; from 14 to 17 medium, above 17 hard.

Absorption. The amount of water absorbed by a rock is generally expressed as the number of pounds of water absorbed per cubic foot. The test is made on a sample of rock about 12 grams in weight which has been thoroughly dried. The sample is first weighed in air, next it is weighed in water just after immersion, and a third weight is obtained of the sample after



Courtesy of the U. S. Office of Public Roads.

FIG. 74. Diamond Core Drill for Preparing Rock Cores for Toughness and Hardness Tests.

it has been immersed for 96 hours. This last weighing is also made in water. The number of pounds of water absorbed per cubic foot of rock is determined by the formula:

$$\frac{W_1 - W_2}{W - W_2} \times 62.37$$

W_1 = weight of sample in water after 96 hours immersion, in grams.

W_2 = weight of sample in water just after immersion, in grams.

W = weight of sample in air, in grams.

62.37 = weight of a cubic foot of water.

Courtesy of the U. S. Office of Public Roads.

FIG. 75. Lap Grinder and Diamond Saw for Preparing Rock Cores for Toughness and Hardness Tests.

Specific Gravity. The specific gravity is determined by weighing a sample 10 to 12 grams in weight first in air and then in water. If

$$W = \text{weight in air,}$$

$$W_1 = \text{weight in water,}$$

$$\text{Specific gravity} = \frac{W}{W-W_1}.$$

The sample should be dried before weighing it in the air. Weighing the sample in water should be accomplished as rapidly as possible, otherwise the rock is liable to absorb water which will introduce an error of unknown amount in the result obtained. The specific gravity of rock dust is determined by means of the Jackson apparatus which will be described in a later chapter.

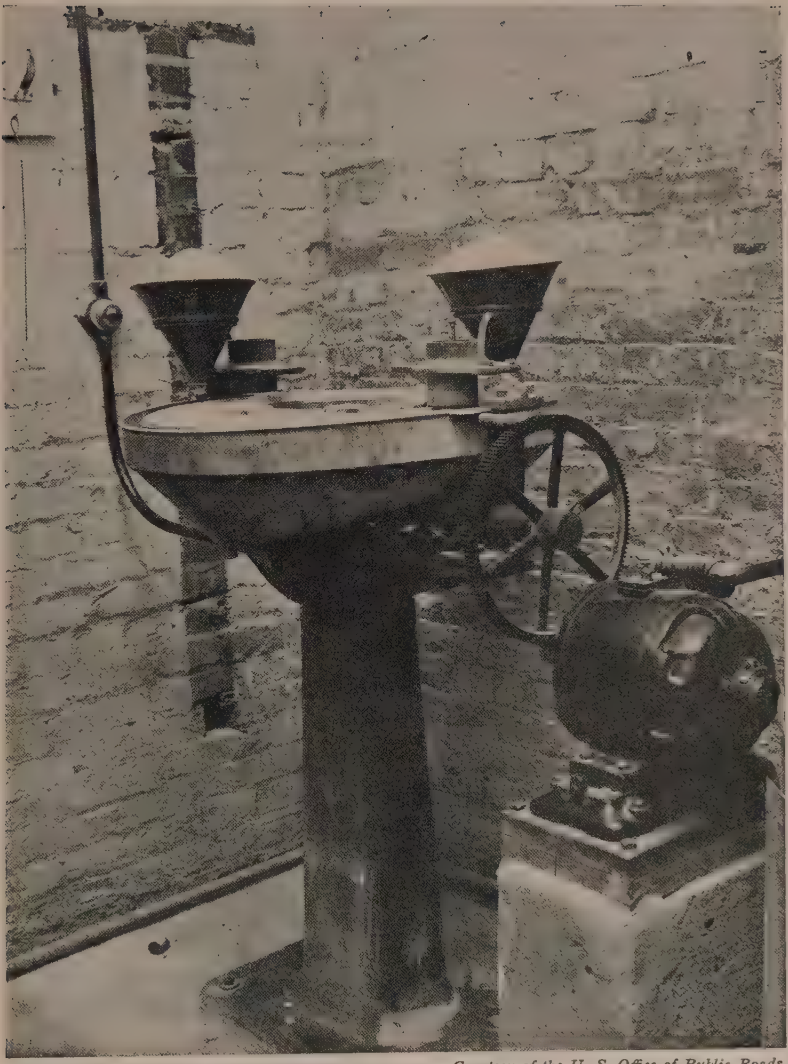
Results of Tests. The average results of the abrasion, cementing power, toughness and hardness for the principal rocks used in road building are given in Table No. 6, which was taken from the U. S. Office of Public Roads Bulletin No. 44. (See page 218.)

Quarrying and Crushing

Stripping the Quarry. Before any drilling is commenced it is necessary to clean off all dirt and disintegrated material from the rock surface. This is called stripping the quarry. Frequently the ledge is exposed so that there is very little of this work to be done. If stripping is not accomplished in a thorough manner and kept well ahead of the drilling and blasting operations, there will always be trouble in having this dirty material mixed with the stone.

Drilling. Drilling is accomplished in several ways: by hammer drills, by churn drills, and by power drills.

Hammer Drills. For quarrying purposes a hammer drill is usually held by one man and struck by two others with hammers. Holes in small boulders may be drilled by the same man both holding and striking the drill. When three men are employed, as above described, the man holding the drill turns the drill slightly after each blow, which keeps the hole circular in shape and prevents the drill from binding. A short drill is used to start with and different length drills are used as the depth of hole increases.



Courtesy of the U. S. Office of Public Roads.

FIG. 76. Dorry Machine.

TABLE No. 6.

Maximum and Minimum Results on Rock Samples, Corrected to January 1, 1912

No. of samples	Name	Specific gravity			Weight—pounds per cubic foot			Water absorbed—pounds per cubic foot		Percent of wear		French coefficient of wear		Hardness		Toughness		Cementing value	
		Max.	*Min.*	*Av.*	*Max.*	*Min.*	*Av.*	*Max.*	*Min.*	*Max.*	*Min.*	*Max.*	*Min.*	*Max.*	*Min.*	*Max.*	*Min.*	*Max.*	*Min.*
16	Amphibolite	3.10	2.70	3.00	193	168	187	1.65	0.04	10.3	1.0	41.7	3.9	19.0	13.5	40	7	235	11
63	Andesite	2.95	1.85	2.65	184	115	165	12.50	.05	17.4	1.5	26.0	2.3	19.4	5.0	44	5	500 +	9
183	Basalt	3.05	2.30	2.85	190	143	178	6.40	.02	16.6	1.3	30.4	2.4	19.3	5.7	40	5	500 +	2
52	Chert	3.00	2.00	2.55	184	125	159	11.10	.25	29.2	2.7	14.9	1.4	19.7	12.7	26	5	500 +	2
9	Conglomerate	2.65	2.00	2.62	165	156	163	3.71	.26	12.7	3.5	11.6	3.2	18.4	9.3	10	10	500 +	20
217	Diabase	3.20	2.60	2.96	200	162	185	2.73	.03	6.3	1.1	36.4	6.4	19.4	12.3	54	4	500 +	2
72	Diorite	3.35	2.70	2.86	209	168	179	1.03	.05	12.0	1.6	25.0	3.3	19.4	16.6	38	4	148	5
183	Dolomite	3.00	2.30	2.73	181	143	170	9.40	.07	18.6	1.2	33.3	2.2	18.8	1.8	27	3	179	9
6	Eclogite	3.65	2.95	3.20	228	184	200	.28	.10	2.9	1.8	22.7	13.8	18.7	17.4	31	14	130	10
11	Epidosite	3.30	2.70	3.04	206	168	190	1.65	.22	7.4	2.0	19.6	5.4	19.3	10.7	23	8	83	3
11	Felsite	2.80	2.50	2.65	175	156	165	3.13	.02	3.4	1.9	21.3	11.8						
91	Fieldstone	.....	.....	.....	.....	.....	.....	.....	.....	10.3	2.1	19.0	3.8	.....	.....	.....	.....	15	12
42	Gabbro	3.65	2.75	2.97	228	172	185	.97	.04	5.9	1.3	30.8	6.8	18.8	13.3	23	8	134	6
152	Gneiss	3.20	2.60	2.75	200	162	172	1.24	.02	16.4	1.7	23.0	2.4	19.3	9.0	25	2	110	1
219	Granite	3.00	2.00	2.66	187	125	166	2.77	.04	24.6	1.1	37.0	1.6	19.6	13.6	33	2	255	2
136	Gravel	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	500 +	3
718	Limestone	2.85	2.00	2.66	178	125	166	13.22	.02	34.2	1.8	21.7	1.2	19.1	.0	25	2	500	9
37	Marble	2.85	2.65	2.76	178	165	172	2.19	.10	14.0	2.3	17.5	2.8	17.3	7.1	23	3	85	10
9	Marl	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	500 +	96
19	Mixed stone	.....	.....	.....	.....	.....	.....	.....	.....	10.3	2.1	19.1	3.9	.....	.....	.....	.....	.....	.....
5	Peridotite	3.55	2.65	2.95	221	165	184	1.02	.27	5.3	3.0	13.2	7.6	15.0	13.3	12	9	91	25
90	Quartzite	3.15	2.35	2.67	196	147	167	2.95	.05	7.6	1.6	24.5	5.3	19.7	15.3	30	5	45	0
42	Rhyolite	2.90	2.05	2.56	181	128	160	7.15	.03	9.7	1.7	23.0	4.1	19.7	15.3	42	6	500 +	9
340	Sandstone	3.25	2.00	2.61	203	125	163	11.60	.02	41.7	1.0	40.8	1.0	19.5	.0	60	2	500 +	1
136	Schist	3.20	2.65	2.94	200	165	183	1.35	.06	23.3	1.3	31.7	1.7	19.0	.9	44	3	232	5
9	Shale	2.70	2.50	2.65	168	156	165	4.84	.50	16.2	3.2	12.6	2.5	17.7	13.9	12	3	367	28
55	Slag	3.90	2.00	2.97	243	125	185	4.40	.04	13.5	2.5	15.7	3.0	18.3	10.7	21	2	500 +	1
59	Slate	3.35	2.60	2.78	209	162	173	2.10	.05	12.4	1.6	24.4	3.2	19.7	1.1	56	1	500 +	1
27	Syenite	3.05	2.15	2.65	190	134	165	4.21	.08	14.4	1.6	25.6	2.8	19.2	17.3	34	8	375	10

Churn Drills. A churn drill is operated by one or more men, depending upon its weight. Until the length of the drill becomes considerable, the weight of the drill is not sufficient to deliver the necessary force to drill the rock and a heavy weight is added to the drill to provide this deficiency. In operating a churn drill the man or men raise the drill and allow it to drop on the rock, giving it a slight turn between blows. Considerable skill has to be exercised in using a drill of this type in order to accomplish effective work.

Power Drills. Power drills are operated by steam, air and electricity. In all of these types the drill is given a reciprocating motion, striking many blows of short stroke to the minute against the rock face. Between each blow the drill bit is given a partial turn. The drills are generally mounted on tripods as shown in Fig. 77. The reciprocating movement in drills operated by steam and air is obtained by admitting the pressure to a cylinder which contains a piston to which is attached the drill bit. In an electric drill this motion is obtained by cams and gears.

Miscellaneous Equipment. A blacksmith's outfit is a necessary part of the equipment in all quarrying operations since the drills have to be constantly sharpened. A boiler to either furnish steam to the drills direct, if steam drills are used, or to run an air compressor, if pneumatic drills are used, is also necessary, the size depending upon the number of drills operated.

Cost of Drilling. The cost and speed of drilling depend upon the kind of rock, the size of hole and the depth of hole drilled.

Gillette gives the following as the speed and cost of hammer drilling holes 6 feet deep, two men striking and one man holding the drill, using a 1½-inch starting bit, the wage rate being $1.75 for a 9-hour day:

	Ft. in 10 hrs.	Cost per foot, cts.
Granite	7	75
Trap (basalt)	11	48
Limestone	16	33

The cost of sharpening drills which would be from 6 to 8 cents per foot should be added to the above.

Courtesy of the Ingersoll, Rand Co.

FIG. 77. Steam Drill.

The following table by Trautwine gives the rate of drilling in different rocks with a churn drill. The drill was operated by one man, starting with a 1¾-inch bit and the depth of holes was 3 feet:

Solid quartz	4 feet in 10 hours.
Tough hornblende	6 " " " "
Granite or gneiss	7.5 " " " "
Limestone	8.5 " " " "
Sandstone	9.5 " " " "

Power drills may be obtained to drill practically any size hole from ¾ of an inch to 3 inches in diameter. As would be expected these drills are capable of drilling at a much more rapid rate than either hammer or churn drills. From about 35 to 75 feet per 10-hour day can be accomplished with a power drill, the rate depending principally upon the kind of rock and the number of set-ups that have to be made.

Explosives. The explosives used in blasting are powder and dynamite. Gunpowder is a combination of saltpeter, sulphur and charcoal, saltpeter being the principal constituent. It is exploded by ignition and in doing so develops gases amounting to almost three hundred times its original volume. Dynamite is simply a mixture of nitroglycerine with an absorbent material, the latter being some kind of mineral matter and gunpowder. Dynamite has about four times the same explosive force as powder. Dynamite does not explode by ignition, but by percussion.

Blasting. A fuse is used to explode powder. To explode dynamite a similar fuse is used which explodes a cap. The cap is placed in one of the sticks of dynamite constituting the charge and the percussion of the cap explodes the dynamite. Instead of using a powder fuse, dynamite is often exploded by means of an electric battery. By this method several charges of dynamite can be set off simultaneously. The cap is fitted with wires through which the current is passed, which heats a very fine platinum wire in the cap and thus ignites it. Prelini states that the energy, released by setting off an explosive, is exerted in all directions or in the form of a sphere, the energy decreasing from

the center towards the surface. If the holes are so drilled and enough explosive is used to shatter the rock at the surface, without throwing it into the air, the full energy of the explosive is taken advantage of without waste. Blasting alone may break up certain kinds of rocks so that very little sledging is necessary to make the rock of a size suitable to be put through a crusher. Ordinarily, however, the pieces have to be broken up by hand into smaller sizes. The openings of a jaw crusher of common size is about 9 by 16 inches. When field stone are used, the boulders are often of such a size that sledging only is necessary to make them suitable for crushing.

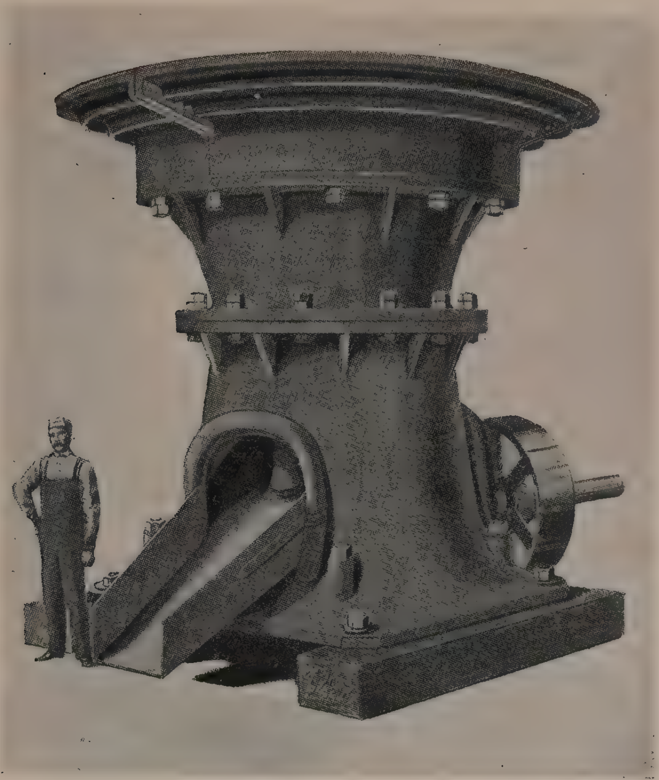
Handling the Rock. The method used in conveying the broken rock to the crusher will depend upon the size and arrangement of the plant. The prime object to be kept in mind is to handle the stone as few times as possible since each rehandling is expensive. Cars running on tracks hauled by horses, cable or engine, and derricks are common in the large plants of the stationary type, while dump wagons are commonly used for portable plants. The stone should be delivered to the crusher platform so that it may readily be fed to the crusher.

Crushing Plants. A complete crushing plant for road-building purposes consists of a boiler, engine, crusher, elevator, screen and storage bins.

Crushers. The crushers are of two distinct types; namely, the gyratory and the jaw crushers. Both types of crushers have some means of regulating the openings so that by using the proper opening together with appropriate crushing plates, almost any size of crushed product can be obtained. The size of the crushed product is limited by the smallest opening between the jaws at the outlet end. The gyratory crusher is a more recent invention than the jaw crusher. That the gyratory crusher produces a more uniform product and is a more durable machine are the main advantages claimed for it over the jaw crusher. With the same horse-power, this type of crusher will generally produce a larger output.

The type and size of crusher to be used depend upon the nature of the rock to be crushed, the size of the product desired

and whether or not the plant is to be permanent or portable. The output of any crusher will depend to a large extent upon the plant arrangement. This latter consideration should be given serious study. It will be found that the smaller the stone is crushed,



Courtesy of the Austin Mfg. Co

FIG. 78. Gyratory Crusher.

the less will be the output of a crusher, since just so much work must be done in crushing the stone.

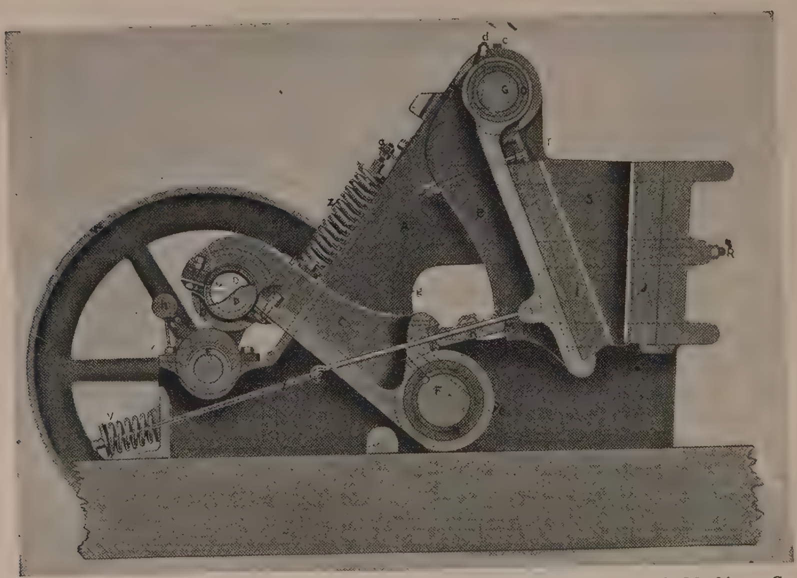
Gyratory Crushers. The gyratory crusher, see Fig. 78, is extensively used for permanent plants. Its great weight and height have not made it generally adaptable for portable plants, although it is sometimes made for this purpose. A description of portable gyratory crushers is given in the following table:

Dimensions of each receiving opening in ins.	7 by 32	8 by 35	10 by 40
Capacity in short tons per hour	10 to 20	20 to 40	30 to 60
Diameter of ring in inches	1.5	2	2.5
Horse power required	15 to 20	18 to 25	22 to 30
Weight of mounted crusher in pounds	12,000	16,000	18,000
Approximate price on wheels	$1250	$1600	$1800

In the following table is given data of gyratory crushers adaptable for permanent plants:

Dimensions of each receiving opening in inches	8 by 30	10 by 38	12 by 44	14 by 52
Capacity in short tons per hour.	15 to 40	30 to 70	50 to 90	80 to 120
Diameter of ring in inches	1.5 to 3	1.75 to 3.5	2 to 3.5	2.5 to 4
Horse power required	14 to 21	22 to 30	28 to 45	50 to 75
Weight of crusher in pounds	20,900	31,200	45,500	64,800
Approximate price	$1400	$1700	$2300	$3000

Jaw Crushers. Jaw crushers are largely used for portable crushers. Fig. 79 shows a sectional view of this type. They



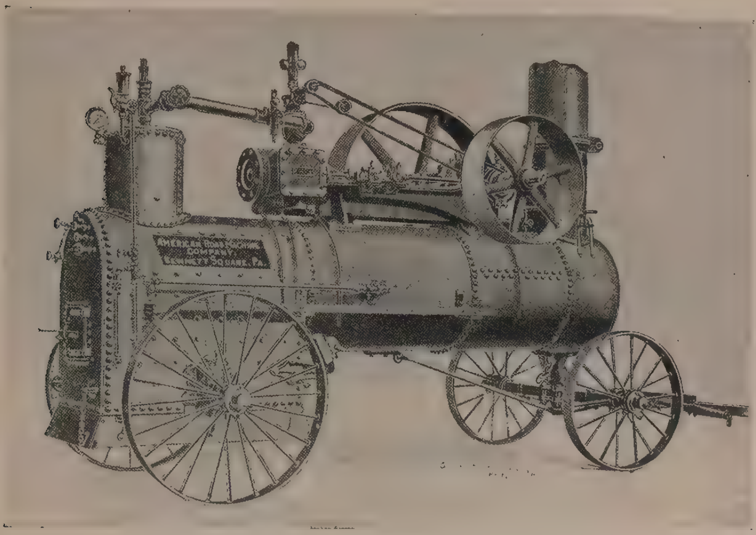
Courtesy of the Good Roads Machinery Co.

FIG. 79. Jaw Crusher, Sectional View.

are placed on a framework which is supported by four wheels. They are designated by the size of the jaw openings at the top.

The size of 8 by 16 inches is very commonly used. The table given below shows the weights and capacities of several typical sizes:

Size of openings in inches	8 by 16	9 by 18	10 by 22
Capacity in short tons per hour	9 to 14	12 to 20	16 to 25
Jaws set to, in inches	2	2	2
Horse power required	12	15	25
Weight of crusher in pounds	7,500	9,600	13,500
Approximate price on wheels	$735	$900	$1400



Courtesy of the Good Roads Machinery Co.

FIG. 80. Portable Boiler and Engine.

Boilers and Engines. The crushers may be run by gasoline engines or by steam engines, the latter being perhaps more common. The steam engine is generally mounted upon a horizontal boiler which is in turn placed on wheels so that it can be easily transported from place to place. This last type of engine and boiler, shown in Fig. 80, is made in sizes capable of developing from 4 to 50 horse power and costs about $30 per horse power. Gasoline engines, which develop from 10 to 25 horse power, cost from $40 to $50 per horse power.

Elevators and Screens. The stone as it comes from the

crusher is carried by means of a bucket elevator to the revolving screen which is fixed over the bin. Fig. 81 shows a rotary screen equipped with a dust jacket. In portable plants the arrangement of the elevator, the screen, and the bins is such that they can be readily dismantled for transportation purposes. The elevators and screens are made in standard sizes, the lengths depending upon the size of the crusher and bin. Considered from the standpoint of durability, unless the elevator is to be

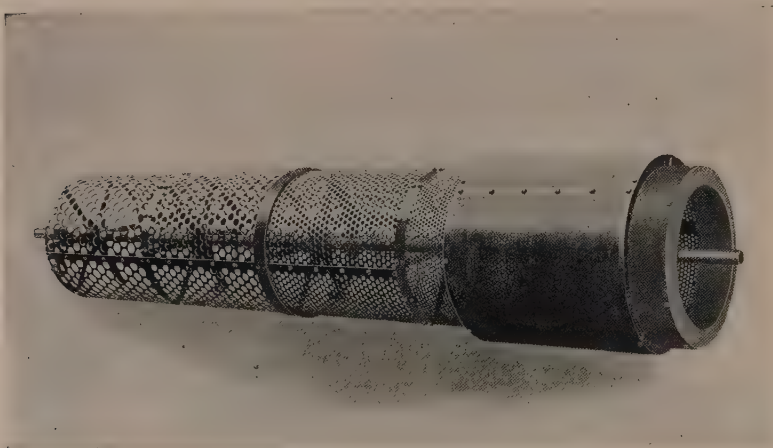
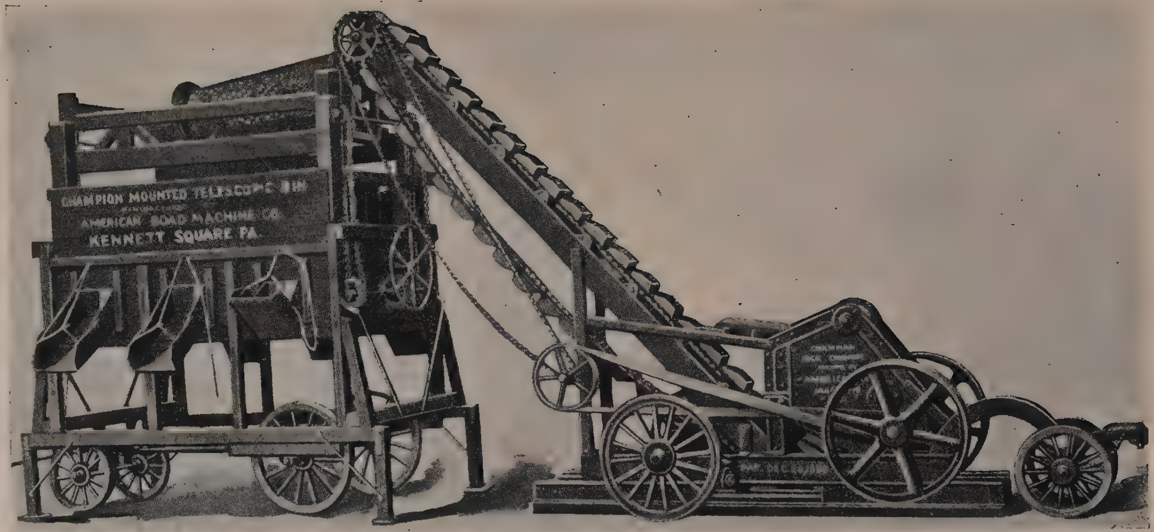


FIG. 81. Rotary Screen.

housed in, the buckets should be fixed to a chain drive rather than fixed to a revolving belt. The prices of screens and elevators with gears and skids depend upon the length and size. A 10-foot screen with gears and skids will cost from $200 to $300. A 16-foot elevator will cost about $300.

Bins. The portable bins are generally made with three compartments. See Fig. 82. These bins are made in sizes varying in capacity from 13 to 50 tons. In some of the more modern types of portable bins, provision is made so that the bin can be raised to a height which will allow teams to pass beneath the unloading chutes. An average price for this type of portable bin is approximately $10 per ton capacity.



Courtesy of the Good Roads Machinery Co.

FIG. 82. Portable Bin and Jaw Crusher with Rotary Screen and Elevator.

Portable Plant. A typical portable plant* for quarrying and crushing rock, grading, hauling and building a macadam road is as follows:

CRUSHER PLANT

1 jaw crusher (9 by 15 inches), with rotary screen	$1,100
Portable bins	200
Engine to drive crusher (15 H.P.)	200
Boiler on wheels (20 H. P.)	600
Total crusher plant	$2,100

QUARRY PLANT

2 steam drills at $250	$ 500
Steam pipe, water pipe, etc	150
Quarry and blacksmith tools	150
Steam boiler (15 H. P.)	400
Total quarry plant	$1,200

ROAD PLANT

6 dump wagons for hauling stone at $125	$ 750
6 dump wagons for grading at $125	750
2 leveling scrapers at $100	200
12 wheel scrapers at $50	600
12 drag scrapers, shovels, picks, etc	150
1 steam roller	2,500
2 sprinkling wagons at $300	600
Gasoline pump and portable water tank	500
Total road plant	$6,050
Grand total	$9,350

Cost of Quarrying and Crushing. The average cost of quarrying and crushing rock at the Pacoima Quarry of the Los Angeles Highway Commission on a six months' run is given in Table No. 7†. The plant includes one No. 4 and one No. 6 Austin gyratory crusher, loading bins, steam shovel, track, quarry cars, electric locomotive, scale house, bunk and boarding house. The labor consists largely of Mexicans, who are paid $2.00 per 8-hour day:

* See Gillette's "Cost Data," page 215.

† See Engineering-Contracting, May 1, 1912.

TABLE No. 7

	Average per ton cents	Percent of total cost
Superintendent and office salaries	1.94	4.21
Stripping, labor	4.19	9.09
Drilling and blasting, labor	.64	1.38
Drilling and blasting, powder	.70	1.52
Drilling and blasting, other material	.03	.06
Loading and transporting, quarry to crusher, labor	19.28	41.82
Loading and transporting, quarry to crusher, material	1.38	3.00
Handling muck, labor	9.20	19.96
Handling muck, material	.28	.60
Plant operation, labor	2.34	5.07
Loading and shipping, labor	.57	1.24
Maintenance, labor	1.19	2.58
Maintenance, material	2.55	5.53
General, labor	.19	.42
General, sundry	.04	.09
Power	1.58	3.43
	46.10	100%

The cost of quarrying and crushing 13,000 cubic yards of rock for a macadam road for a State Highway in Missouri, built in 1908, is given in Table No. 8.*

TABLE No. 8

Quarrying	Rate	Cost per cu. yd. in road	
Foreman and timekeeper	$0.40	$0.056	
Drillers (Hand)	.17½	.018	
Drillers (Steam)	.17½	.031	
Laborers	.17½	.224	
Teams	.35	.021	
Powder, lbs	.10	.059	
Caps	.10	.002	
Fuse, ft	.01	....	
Watchman	.15	.017	
Water boy	.10	.012	
Quarry rent	...	.030	
		$ .470	.470
Crushing			
Foreman and timekeeper	.40	.064	
Laborers	.17½	.121	
Engine and engineer	.40	.067	
Watchman	.15	.007	
		.259	.259
Grand total			$.729

* See Engineering-Contracting, August 4, 1909.

Voids and Weights of Crushed Stone. When rock is crushed it occupies a larger volume than it did in place due to the voids in the mass. The amount of voids is variable depending upon the proportions of the sizes in the mass. The manner in which the stone is placed in a bin, cart, car or barge, and the length of haul also affect the amount of voids. Gillette gives the following, showing the number of cubic yards of broken stone with varying percentages of voids that can be obtained from 1 cubic yard of solid rock:

Voids	30%	35%	40%	45%	50%	55%
Cubic yards of broken stone from 1 cubic yard of solid rock	1.43	1.54	1.67	1.82	2.00	2.22

The specific gravities of the various rocks used for building roads is given in Table No. 6. If the voids in the mass are known, therefore, the weight of any volume can be computed. It is quite important to know this point when buying or selling stone by the ton, when the tonnage is computed from the cubical contents of the mass. As the specific gravity of different kinds of rock is not the same, the weight of a mass of crushed stone will depend upon these two factors.

The following methods have been used in determining the voids in mineral aggregates.

Pouring Method. In this method a suitable receptacle is filled with the dry aggregate to be tested, the aggregate being firmly compacted. Water is then poured into the receptacle until it is flush with the surface of the compacted aggregate. The amount of water used is considered the amount of voids in the mass of the aggregate.

New York State Method. This method is a modification of the pouring method in that the water is introduced into the bottom rather than the top of the receptacle. The apparatus consists of a 1000 cubic centimeter receptacle open at the top and closed at the bottom, with the exception of a small orifice which is connected by means of a rubber tube to a graduated burette. The aggregate is placed in the receptacle and com-

pacted. The burette is then filled with water. The water is allowed to run into the receptacle through the orifice in the bottom. When the water is flush with the surface of the compacted aggregate the flow is cut off. By means of the burette, the quantity of water introduced is measured and this amount is considered to represent the voids in the mass.

U. S. Office of Public Roads Method. A 1000 cubic centimeter cylindrical receptacle, open at both ends, is placed on a sheet of paper and filled with the compacted aggregate. The cylinder is lifted up, allowing the aggregate to remain on the paper. The aggregate is then poured into a 2000 cubic centimeter graduated flask which has previously been filled with 600 cubic centimeters of water. The displacement of the water in the flask is noted. The amount of voids in the mass is determined by subtracting the final reading of the meniscus from the initial reading plus 1000, or 1000 + 600 − the final reading equals the amount of voids.

Schutte Method. In this method a can having the shape of a truncated cone is used. It is necessary in using this method to determine the specific gravity of the aggregate. The weight of the cone full of the compacted aggregate is determined and next the weight of the cone full of water. Knowing the weight of the cone the net weight of aggregate and water can be found. The weight of the water in the cone multiplied by the specific gravity of the aggregate gives the weight of the aggregate if it was a solid mass without voids. This computed weight minus the weight of the compacted aggregate in the cone gives the amount of voids in the mass.

Table No. 9* gives the voids in loose broken stone of different kinds and sizes according to Gillette.

Construction

Historical. The following statements which are quoted from remarks of Tresaguet and McAdam serve to describe the methods which they advocated.

*See Gillette's "Cost Data," page 174.

In a paper presented before an assembly of the Ponts et Chaussées, in 1776, Tresaguet described his method of building roads as follows: "In order to successfully diminish the thickness of the roads and give them sufficient strength to sustain

TABLE No. 9.

VOIDS IN LOOSE BROKEN STONE.

Authority	Percent Voids	Remarks
Sabin	49.0	Limestone, crusher run after screening out ⅛-in. and under
Sabin	44.0	Limestone (1 part screenings mixed with 6 parts broken stone).
Wm. M. Black	46.5	Screened and washed, 2 ins. and under.
J. J. R. Croes	47.5	Gneiss, after screening out ¼-in. and under.
S. B. Newberry	47.0	Chiefly about egg size.
H. P. Boardman	39 to 42	Chicago limestone, crusher run.
E. P. Boardman	48 to 52	Chicago limestone, screened into sizes.
Wm. M. Hall	48.0	Green River limestone, 2½ ins. and smaller, dust screened out.
Wm. M. Hall	50.0	Hudson River trap, 2½ ins. and smaller, dust screened out.
Wm. B. Fuller	47.6	New Jersey trap, crusher run, ⅙ to 2.1 in.
Geo. A. Kimball	49.5	Roxbury conglomerate, ½ to 2½ ins.
Myron S. Falk	48.0	Limestone, ½ to 3 ins.
W. H. Henby	43.0	Limestone, 2-in. size.
W. H. Henby	46.0	Limestone, 1½-in. size.
Feret	53.4	Stone, 1.6 to 2.4 ins.
Feret	51.7	Stone, 0.8 to 1.6 ins.
Feret	52.1	Stone, 0.4 to 0.8 in.
A. W. Dow	45.3	Bluestone, 89% being 1½ to 2½ ins.
A. W. Dow	45.3	Bluestone, 90% being ⅙ to 1½ ins.
Taylor & Thompson	54.5	Trap, hard, 1 to 2½ ins.
Taylor & Thompson	54.5	Trap, hard, ½ to 1 in.
Taylor & Thompson	45.0	Trap, hard, 0 to 2½ ins.
Taylor & Thompson	51.2	Trap, soft, ¾ to 2 ins.
G. W. Chandler	40.0	Canton, Ill.
Emile Low	39.0	Buffalo limestone, crusher run, dust in.
C. M. Saville	46.0	Crushed cobblestone, screened into sizes.
I. O. Baker	43 to 47	Crushed limestone in sizes
A. N. Johnson	41 to 51	Crushed limestone in sizes.
W. E. McClintock	47.0	Crushed trap.

the loads which they have to carry, it is necessary to modify the method of construction. . . . The bottom or earth foundation on which the first layer rests is made parallel to the finished surface of the road. The depth is reduced to 10 inches and the slope of the surface is made about 20 degrees with the horizontal.

The first layer of stone is placed on edge similar to block paving, and is firmly compacted. More stone is likewise placed layer by layer on this course and is broken into coarse pieces, which so interlay that no voids are left. Finally a top layer 3 inches thick is added. The stones in this layer are of the size of a walnut and are obtained by breaking the stone with small hammers on special anvils. This layer is placed by means of shovels so as to correspond with the desired shape of the road. Particular attention should be given to the choice of stone for this last course since the strength of the pavement depends on it and one cannot be too careful as to the quality of the stone selected. This may necessitate at times a different grade of stone for the top course than that which was used in the lower courses."

McAdam said in various reports presented by him during the period from 1811 to 1820: "The stone laid in the road is to be loosened up and broken so as no piece shall exceed 6 ounces in weight. The road is then to be laid as flat as possible, a rise of 3 inches from the center to the side is sufficient for a road 30 feet wide. The stones, when loosened in the road, are to be gathered off by means of a strong, heavy rake, . . . to the side of the road, and there broken, and on no account are stones to be broken on the road. When the great stones have been removed and none left in the road exceeding 6 ounces, the road is to be put in shape and a rake employed to smooth the surface which will at the same time bring to the surface the remaining stone and will allow the dirt to go down. When the road is so prepared, the stone that has been broken by the side of the road is then to be carefully spread on it. This is rather a nice operation, and the future quality of the road will greatly depend on the manner in which it is performed. The stone must not be laid down in shovelfuls but scattered over the surface, one shovelful following another and spreading over a considerable space. Every road is to be made of broken stone without mixture of earth, clay, chalk, or any other matter that will imbibe water, and be affected with frost: nothing is to be laid on the clean stone on pretence of binding; broken stone will

combine by its own angles into a smooth solid surface that cannot be affected by vicissitudes of weather, or displaced by the action of wheels, which will pass over it without a jolt and consequently without injury. The size of stones for a road has been described in contracts in several different ways, sometimes as the size of a hen's egg, sometimes at half a pound weight. These descriptions are very vague, the first being an indefinite size and the latter depending upon the density of the stone used and neither being attended to in the execution. The size of stone used on a road must be in due proportion to the space occupied by a wheel of ordinary dimensions on a smooth level surface, this point of contact will be found to be, longitudinally about an inch, and every piece of stone put into a road, which exceeds an inch in any of its dimensions, is mischievous.

"At one time I formed the opinion that the use of a large stone foundation was only a useless expense, but experience has convinced me that it is likewise positively injurious. It is well known to every skillful and observant road maker that if strata of stone of various sizes be placed as a road, the largest stones will constantly work up by the shaking and pressure of traffic, and that the only mode of keeping the stones of a road from motion is to use materials of a uniform size from the bottom. In roads made upon large stones as a foundation, the perpetual motion, or change of position of the material, keeps open many apertures through which the water passes. . . . The first operation in making a road should be the reverse of digging a trench. The road should not be sunk below but rather raised above the ordinary level of the adjacent ground, care should at any rate be taken that there is sufficient fall to take off the water, so that it should always be some inches below the level of the ground upon which the road is intended to be placed. This must be done either by making drains to lower the ground water, or, if that be not practicable, from the nature of the country, then the soil upon which the road is proposed to be laid must be raised by addition so as to be some inches above the level of the water. Having secured the soil from under water, the road maker is next to secure it from rain water, by a solid road, made of clean

dry stone or flint, so selected, prepared and laid, as to be perfectly impervious to water. The thickness of such a road is immaterial, as to its strength for carrying weight; this object is already obtained by providing a dry surface. . . . Several new roads have been constructed on this principle within the last three years. . . . None of these roads exceeds 6 inches in thickness, and although that on the great north road is subjected to a very heavy traffic, it has not given way, nor was it affected by the late severe winter."

Size of Stone. The sizes of the stone used vary in different specifications. Since nearly all of the broken stone used for road construction is screened with a rotary screen, it should be noted that the speed at which the screen is revolved, the pitch, the length and the size of the holes in the screen all influence the grading of the stone into different sizes. The type of crusher used and the kind of rock crushed also influence the amount of the different sizes obtained. The width of the jaw opening of the crusher determines the maximum size of stone which will be obtained from crushing any rock. The stone will be broken into sizes varying from this maximum down to dust.

Common commercial sizes of broken stone are screenings, ⅜-inch chips, ½, ¾, 1, 1¼, 1½, 2, 2¼, 2½, and 3 inches. In designating the sizes of broken stone, the longest dimensions of the product have been stated or the stone has been described, for instance, as 1½-inch stone, etc. In the last case, however, the size of product obtained will be extremely variable unless the size of holes in the screen through which this product must pass is stated. The scientific method of describing the size of stone is to stipulate that it shall pass over a screen having holes of one size and pass through a screen having another size of holes, or that it shall pass a screen having holes of one size and be retained on a screen having another size of holes. At the various quarries in New York State, sizes of crusher run stone in 1912 were designated as follows:

SCREENINGS.	That product of the ordinary run of the crusher passing a ½-inch or ⅝-inch circular opening including the dust of fracture.
¾-INCH STONE.	Crusher run retained on the ½-inch or ⅝-inch opening and passing a 1⅛-inch or 1¼-inch opening.
1½-INCH STONE.	Crusher run retained on the 1⅛-inch or 1¼-inch opening and passing the 2¼-inch opening.
2½-INCH STONE.	Crusher run retained on the 2¼-inch opening and passing the 3¼-inch opening.

Screenings which are screened to remove practically all stone dust passing over a ¼-inch or ⅜-inch screen are designated as ⅜-inch stone.

Sizes Used in Different Courses. Broken stone roads are ordinarily built in three courses. The larger size products of the crusher are used in the first or foundation course. Gravel and slag are sometimes substituted for broken stone in the foundation course. The size of stone for this course varies from 1 to 3 inches in longest dimensions. The second course is composed of stone slightly smaller, ranging from 1 to 2 inches or from ½ inch to 1¼ inches in their longest dimensions. The top course consists of screenings varying from ½ inch down to dust.

The sizes of stone, as specified in some of the different States of the United States, are as follows:

STATE	FOUNDATION COURSE	UPPER COURSE
Massachusetts	1¼ to 2½ inches.	½ to 1¼ inches.
New Jersey	2½-inch stone or stone that will pass a 3-inch ring, minimum length 2 inches.	1½-inch stone or stone that will pass a 2-inch ring, maximum length 2 inches, minimum length 1 inch.
New York	Through 3½-inch holes.	Through 2¼-inch holes.
Maryland.	3- to 1-inch, maximum length 3 inches.	1- to 2-inch, maximum length 2 inches.

Aitken states that the broken stone roads in Great Britain have a foundation layer of stones varying in size from 3 to 4 inch-cubes, while the upper course is composed of broken stone varying in size from 2 to 2¼ inches.

In France the size of the stone used varies from about 1¼ to 3 inches, the size frequently adapted being 2¼ or 2¾ inches.

Foundation and Subgrade. The lower or foundation course of a macadam road may be strengthened by a telford base, a V-drain, or by increasing its thickness. The construction of telford and V-drain foundations has been described in Chapter VI. When traffic and soil conditions are favorable, however, it is customary to build the foundation course directly upon the subgrade. It is assumed, of course, that the roadbed has been properly drained according to methods set forth in Chapter V. The subgrade is a shallow trench composed of two or more planes or a curved surface sloping from the center to the sides. The surface of the subgrade is generally parallel to the finished surface of the macadam, although this is not true when the depth of stone at the edge of the shoulder is made less than at the center. The subgrade is the same width as the broken stone surface. The sides of the trench, which serve to hold the stone in place, are formed by earth shoulders, generally from 3 to 5 feet in width. In places where the edge of the stone is bounded by a curb or gutter the earth shoulder is generally omitted unless the roadway is extremely wide and only a partial width is built of macadam. The subgrade should be brought to true line and grade and be thoroughly compacted with a steam roller. Any low spots which appear during compaction should be brought up to grade with good material and rerolled.

Form of Section. Formulas for crown or transverse slope suitable for macadam are given in Chapter IV. As previously stated, the crown ordinarily used is from ½ to ¾ of an inch to the foot. Typical cross-sections of broken stone roads, as constructed by different State Highway Departments, are shown in Chapter IV.

Hauling the Stone. Stone may be hauled to the road by means of any of the various carts or wagons described in Chapter VII. Patent bottom dump wagons with doors hinged on the sides or on the ends of the wagons are commonly used and serve the purpose in an excellent manner. It is possible with this type of wagon to regulate the size of opening between the bottom doors so that any width of opening up to the full opening can be obtained. By this means it is possible to spread the stone in

layers as the wagon is drawn along the road. Similar wagons are built to be used with a traction engine. Wagons of this type generally have a capacity of 3 to 4 cubic yards and are drawn in

FIG. 83. Truck Used for Hauling Stone in England.

trains. The wagons are connected to each other so that they will readily follow the path taken by the traction engine, no steering of the individual wagons being necessary.

Laying the Stone. It is apparent that in foreign practice somewhat larger stones are employed for the upper course than are commonly used in this country. In some cases where the stone is not of a particularly good quality, better results may be obtained by placing the smaller stone in the bottom of the road and the larger sized stone on top. There are also cases where the run of the crusher from the coarse sizes down to dust is placed on the road as one course, but this method is not recommended. If the stone is brought in patent bottom dump wagons, it may be dumped directly upon the subgrade and spread with

forks or with a stone spreading machine. Stone brought to the work for the upper courses of a road, however, should be dumped on boards and shovelled in place to prevent the segregation of the sizes, which might occur if the stone was dumped directly upon the road from the wagons.

Thickness of Courses. The thickness varies in different specifications and is governed by the amount of traffic which the road is to receive, and the condition of the subgrade. For the foundation course common values are 4, 6, and 8 inches in total thickness after rolling where the subgrade furnishes a good natural foundation. The upper course is generally from 2 to 3 inches in thickness after rolling. The stone surfacing is sometimes made the same thickness throughout its width and again some engineers believe in economizing by making the thickness of the stone at the sides from 1 to 2 inches less than the depth at the center, the theory being that the sides do not receive as much wear as the center. Under present traffic conditions and especially where heavy motor trucks are used, the practice of reducing the thickness of material at the sides is questionable.

In England, Aitken states that the foundation layer of 3 to 4-inch stones is made from 6 to 9 inches deep in country districts and is increased to 12 inches for suburban and town roads. A cushion layer of sand from 1 to 1½ inches thick is spread over the foundation to prevent the stone in the upper course from being crushed upon the hard foundation. The upper course of broken stone is made from 4 to 6 inches thick and is constructed in two layers when a thickness of 6 inches is used.

H. E. Stilgoe, in speaking of the roads in Birmingham, England, in 1909, recommended a thickness of 7 inches for first-class streets, the stone to be laid in two courses.

Regulating the Thickness. To gauge the thickness of a layer of stone, wooden cubes made equal to the depth of a layer are sometimes placed at intervals across the roadway and the stone is filled in to the tops of them, the cubes being taken up and moved along as the work progresses. With this method, however, if there are any irregularities in the subgrade or in the foundation course, they will be carried up to the finished surface. A better

method of regulating the depths of the different layers is to set strings longitudinally at the proper elevation at the sides and center of the roadway. In this manner the elevations are always tied in with the finished grade and any irregularities can more readily be corrected as they occur.

Rolling the Stone. The courses are each laid to the required thickness and separately rolled before the next course is placed. The roller used in compacting this material should be at least 10 tons in weight. Fig. 90 shows a three-wheel roller of this type. Rolling should commence at one edge of the roadway and progress towards the center, the roller traveling in a direction parallel with the center line of the road. After reaching the middle of the road, the roller should pass to the other side, and again work in a similar manner towards the center. This method of rolling keeps the road in shape and prevents either pushing the crown out of line or flattening it. Careful rolling is absolutely necessary in order to obtain a good shape to the road surface. A steam roller is much more effective than a horse roller since the latter is lighter and hence cannot compact the surface as thoroughly. Moreover, the horses' hoofs tend to loosen the surface during compaction, which makes it difficult to secure good results. If, in the first passages of the roller over the surface, any low spots are detected, they should immediately be brought to the proper level by the addition of more stone of the same size as is used in the course being rolled, before further compaction takes place. It will be found in rolling that broken stone will be compressed about 33 percent, that is, to make a compacted layer 2 inches thick, 3 inches of broken stone would have to be spread loose.

In some specifications it is stated that the voids in the foundation course shall be filled with stone screenings, sand or gravel, the fine binding material to be thoroughly swept in, watered, and rolled. No surplus material, however, is allowed to remain on the surface of the foundation course. This method of construction provides a firmer foundation than where the voids between the stones are not so filled. The same treatment is also frequently used to facilitate the rolling of the foundation course where the

stone is of such a character that it will not readily compact under the action of the roller.

Applying the Screenings. Screenings are always used in connection with the construction of the upper course. When this course has been firmly compacted, the surface is covered with a layer of stone screenings and thoroughly sprinkled with water, which washes the screenings into the voids in the stone. More screenings are added as desired and rolling is continued, the surface being sprinkled in front of the roller. When the proper amount of water and screenings have been used, a wave of grout will be pushed along in front of the roller. A coating of screenings should be laid over the entire surface, no more being used than is necessary to cover the stone. The stone screenings resulting from the crushing of the rock with which the first two courses are filled are generally used for the binder. When this material is unsuitable, clay, loam, sand, or screenings of a different rock are substituted for it.

Cost of Broken Stone Roads. Table No. 10 shows the character and cost of water-bound macadam roads in 1911 in several cities.

TABLE No. 10

Cost of Water-Bound Macadam in Several American Cities in 1911.
From *Engineering & Contracting*, April 3, 1912.

City	Square Yards Including Grading	Cost per Sq. Yd.	Thickness of Macadam, Inches
Boston, Mass.	30 753	$.75	6
New Bedford, Mass.	83,424	.51	12
East Providence, R. I.	26,844	.52	6
Mt. Vernon, N. Y.	8,000	.95	8
Plattsburgh, N. Y.	14,090	.80	6
Trenton, N. J.	4,926	.85	8
Bloomington, Ind.	10,000	.45	10
Rockford, Ill.	57,420	.44	9½
Keokuk, Ia.	36,000	.90	9
Lexington, Ky.	15,000	.80	6½
Muskogee, Okla.	12,000	1.05	9

During 1910 and 1911 quotations on the price of broken stone delivered at New York were 85 cents to $1.00 per cubic

yard and at Boston 64 to 85 cents f.o.b. at the quarry, varying slightly for different gauges. At Paconia, Cal., the cost was 53.5 cents per ton at the plant. The cost per cubic yard of stone compacted in place varies between $2.50 and $4.00. An average cost is $3.00.

The cost of the construction of macadam roads can probably be best illustrated by the following tables. The labor costs of handling the stone on the road do not differ essentially, but the labor costs of getting the stone to the road vary, depending upon the way the stone is shipped, the length of haul, and the means used to haul the stone. The cost of the stone itself is also a variable factor. The cost of crushing and quarrying broken stone has been previously given. Table No. 11 shows the labor costs of several macadam roads constructed by the Illinois Highway Commission in 1908 and 1909:

TABLE No. 11

From *Engineering & Contracting*, October 11, 1911.

Cost per Cu. Yd. for Placing Stone	No. 1	No. 2	No. 3	No. 4
Unloading stone	$.07	$.12	$.15	$.11
Hauling stone	.22	.53	.37	.20
Spreading stone	.04	.07	.06	.06
Rolling and sprinkling	.07	.08	.06	.05
Watchman and miscellaneous labor	.01	.01	.05	.01
Coal, oil, and supplies	.02	.04	.02	.04
Total	$.43	$.85	$.71	$.47

Labor Cost per Sq. Yd. Finished Macadam	No. 1	No. 2	No. 3	No. 4
Superintendence	$.015	$.033	$.120	$.014
Excavation	....	.094	.056	.055
Shaping roadbed	.012	.015	.012	.007
Trimming shoulders	.005	.013	.021	.007
Placing stone	.121	.285	.222	.190
Applying gravel binder	....	.016	....	....
Total	$.153	$.456	$.431	$.273
Average length of haul, miles	3/5	1¼	⅜	1
Labor cost, cents per hour	17½	20	19–20	15
Teams, cents per hour	37½	50	37½	30

The item "unloading stone" in the above table is the cost

of unloading from cars to storage. To obtain the total cost of stone in storage piles, the two items, "unloading stone" and "hauling stone," should be added.

The following cost data* are used in making office estimates of the cost of state roads in New York State. The items are based largely upon costs taken from actual work:

Rock Excavation.	Price Per Cu. Yd.
Large boulders (for which 10 cu. yds. a mile are allowed on all estimates)	$1.50
1. Steam drill work, limestone	1.25
1. Steam drill work, granite	1.50
2. Hand drill work, limestone	2.00
2. Hand drill work, granite	2.00

Field Stone Sub-Base.

A sub-base course 6 ins. deep, made of the usual size fence stone, requires 1 cu. yd. loose for 1 cu. yd. rolled.

12 ins. deep requires 1.25 cu. yds. loose.

Cost of cobbles, per loose cu. yd	$0.10	Multiply these items by 1.25 for 12-inch depth of sub-base.
Loading cobbles, per loose cu. yd	0.15	
Hauling cobbles 1 mile, per loose cu. yd	0.35	
Placing cobbles, per loose cu. yd	0.10	
Rolling cobbles, per loose cu. yd	0.05	

If fence stone are used in place of cobble, 10 cents per loose cubic yard should be added to the above cost for sledging.

Filler for Sub-Base Course.

⅓ cu. yd. per cu. yd. rolled sub-base.

Cost ⅓ cu. yd. at pit or crusher	–.—
Loading ⅓ cu. yd	$0.05
Hauling ⅓ cu. yd. 1 mile	0.10
Spreading ⅓ cu. yd	0.04

Broken Stone for Bottom Course.

Labor.

Unloading.	
Under 2,000 cu. yds. (shovelling)	$0.15 per cu. yd.
Over 2,000 cu. yds. (elevator)	0.10 per cu. yd.
Hauling (Teams).	
Bad conditions	0.35 per yd. mile.
Average conditions	0.30 per yd. mile.
Good conditions	0.25 per yd. mile.
Mechanical hauling	0.15 per yd. mile.

* See "Cost Data on Bituminous and Water-bound Macadam Roads," by W. G. Harger, *Engineering News*, July 13, 1911.

Spreading.
- $5\frac{1}{3}$ ins. loose depth........................ $0.06 per cu. yd.
- $4\frac{1}{3}$ ins. loose depth........................ 0.08 per cu. yd.

Rolling .... 0.05 per cu. yd.

FILLER FOR BOTTOM COURSE.

0.35 cu. yd. per cu. yd. rolled bottom course.

Cost of 0.35 cu. yd. at pit or crusher.......................... –.—
Loading 0.35 cu. yd.. $0.05
Hauling 0.35 cu. yd. 1 mile at $0.35 per yd. mile............ 0.12
Spreading and brooming 0.35 cu. yd........................ 0.07

BROKEN STONE FOR UPPER COURSE, SHIPPED IN BY CARS.

Labor.
Unloading (same as bottom)
Hauling (same as bottom)
Spreading.. $0.08
Rolling.. 0.04
Puddling... 0.06

SCREENING FOR UPPER COURSE.

Screenings.
Unloading by hand, 0.5 cu. yd.............................. $0.07
Hauling 0.5 cu. yd. 1 mile................................. 0.15
Spreading 0.5 cu. yd.:
- by cross dump wagons..................................... 0.03
- by hand.. 0.07

COST OF QUARRYING AND CRUSHING LOCAL STONE.

Field Stone.

1 cu. yd. field stone equals 1 cu. yd. crushed.
1.8 cu. yd. field stone equals 1 cu. yd. No. 3 and 4 rolled

Cost 1 cu. yd. field stone...................... $0.10 per cu. yd.
Blasting or sledging per cu. yd.
actually blasted or sledged .... 0.40 per cu. yd.
Loading 1 cu. yd. field stone.................. 0.15 per cu. yd.
Hauling 1 mile field stone.....................0.35 per cu. yd.
Crushing 1 cu. yd. field stone:
- Sandstone (soft)........................... 0.10 per cu. yd.
- Limestone.................................. 0.15 per cu. yd.
- Granite and trap rock...................... 0.20 per cu. yd.

Quarried Stone.
Limestone, quarrying........................... $0.50 per cu. yd.
Conglomerate, quarrying........................ 0.80 per cu. yd.
Trap, quarrying................................ 0.70 per cu. yd.
Crushing (same as above)....................... –.— per cu. yd.
Total cost in bins......................... –.— per cu. yd.

The crushing cost does not include repairs to crusher.
The crushing is taken from previously given cost data.
The item of quarrying includes delivering to crusher.

Maintenance

Causes of Wear. Water, if allowed to stand on a macadam surface, will soften the latter and cause it to rapidly wear out. When the frost is coming out of the ground in the spring, the surface will also be in a soft condition and require attention. The effect of horse-drawn vehicle traffic is frequently observed in the formation of the "horse path," so-called, at the center of the road. If the surface is given a flat crown, this will be prevented

Fig. 84. Mosaic Condition of a Macadam Surface after Binder Has Been Swept Away by Traffic.

to some extent since the traffic will be encouraged to use the entire width of surface. If the teams track each other the wheels will form ruts, particularly when the road is in a soft condition. The grinding action of the wheels wears the stone and forms dust which, in a dry state, is swept away by the wind, thus leaving the stones in the top course exposed, in which condition they are liable to be displaced by the action of traffic. A heavy traffic of motor cars traveling at high speed will also cause the macadam

surface to ravel very quickly when the mosaic of the upper course is exposed. Sometimes when the road is in this condition and the weather has been dry, a concentrated motor traffic of only one or two days' duration will cause ravelling. Fig. 84 shows the mosaic condition of the surface when the binder has been swept away, and Fig. 85 illustrates how a concentrated motor traffic of short duration will ravel the surface. Fig. 86 shows

FIG. 85. Effect of Motor-Car Traffic on a Macadam Surface.

how the surface is worn out on the inside edge of a curve, as a result of motor-car traffic. A road which is not kept in repair very quickly becomes a bad road. With proper attention, however, the surface can be kept in a passable condition and the life of the road be considerably prolonged.

ORDINARY REPAIRS. To provide against failure from any of the causes enumerated above, the following essential principles of maintenance work are given. At all times the surface of the road should be kept smooth. This enables the road to shed water more readily and eliminates shocks which would result from the traffic where the surface is uneven. Any hollows or

pot-holes, see Fig. 87, which develop in the surface should be filled in as soon as formed. Particular attention should be given to eliminating the ruts, since any depressions in the surface hold the water, soften the road, and are enlarged very rapidly by the action of traffic. Broken stone of the same size as is used in the upper course should be used in filling in the depressions and ruts. Ordinarily screenings are added and the stone is tamped

FIG. 86. Wear on the Inside of the Curve Produced by Motor-Car Traffic.

down, leaving the surface higher than the surrounding surface of the road, in order to allow for compaction by traffic. The mud should always be removed from the depressions before the new stone is added. In repairing pot-holes in France and England, it has been found that the best results are obtained if the holes are cut out on the lines of a square or rectangle which is of sufficient area to include the depression, the sides to be cut through for the full depth of the wearing surface. The stone is replaced, carefully tamped, filled with screenings and puddled, or it is incorporated with some bituminous material either before or after placing. Rolling in the spring of the year when the

road is soft will be of great help in providing a smooth surface for the remainder of the season. An excess of dust or mud on the surface should be removed, since dust is not only very objectionable from the standpoint of comfort to the traffic, but when wet it forms mud which keeps the surface of the road in a moist condition, sometimes for a long period. On the other hand, when the upper course of stone presents a mosaic surface, sand, stone

FIG. 87. Pot-hole in a Macadam Surface.

screenings, or other binding material should be spread on the surface to prevent ravelling.

The earth shoulder between the stone surfacing and the ditch should be trimmed up from time to time, so that water flowing from the surface of the road will not be impeded in its progress to the ditch. This work can be done in a satisfactory and economic manner many times by the use of a road scraper. The material removed from the shoulders, however, should never be thrown up into the center of the stone surface. As is the case in earth and gravel roads, the ditches and drains should be carefully looked after to provide for the ready flow of water.

The majority of these ordinary repairs should be accomplished under what is called the continuous system of maintenance—that

Courtesy of the Buffalo Steam Roller Co.

FIG. 88. Roller with Picks in Wheels.

is, a system where the roads are constantly looked after and any necessary repairs are immediately attended to. The continuous

system of maintenance is probably not only the cheapest in the end, but it also keeps the road in a good state of repair. The patrol system of maintenance as carried out in France is a good illustration of what can be accomplished by this method. This system is gradually being adopted in different parts of the United States, but New York is thus far the only State that has adopted this system on extensive lines. There are many municipalities which have very efficient Public Works Departments by means of which the streets are maintained in an excellent manner.

Resurfacing. When the road becomes so badly worn that it is impossible to keep it in good condition by the ordinary methods of maintenance, resurfacing is necessary. Unless an average depth of stone of about 3 inches is to be added, the old macadam surface should be picked up or scarified so that the new stone will bond with the old. The wheels of a steam-roller are so made that it is possible to insert heavy picks or spikes in the rear wheels, as is shown in Fig. 88. In repairing the state roads in Massachusetts, a common method is to place picks in the wheels of the roller and to drag a heavy spike harrow behind the roller. A few trips of these machines will loosen up the surface. The surface is then worked over with a light hand harrow or a farmer's spring tooth weeder to bring the stone to the surface and to shake the dirt down beneath. The new stone is added wherever required to bring the surface to the proper shape, and the surface is then thoroughly rolled and puddled, as in constructing a new road. The roller picks will loosen the road to a depth of from 4 to 6 inches.

Scarifiers are also commonly used in resurfacing work. With some types of scarifiers the picks may be set so that practically any depth from 1 to 6 inches can be loosened. The scarifier tends to bring the stone to the surface and to shake the dirt down underneath as may be seen by Fig. 89. It will be necessary, however, to shape up the surface with a harrow or with rakes. The work of scarifying or picking will be much more readily accomplished if the surface is first soaked with water.

Cost of Maintenance. Previous to 1907, the cost of maintaining the state roads in Massachusetts, built of water-bound

Courtesy of the Buffalo Steam Roller Co.

FIG. 89. Scarifier at Work.

macadam, was about $200 per mile, the average width being 15 feet.

The cost of resurfacing roads in the northeastern part of the United States may be estimated as about 10 cents per square yard for each inch of new stone to be added.

Cost of Loosening. Gillette gives as the cost of picking an old limestone macadam surface to a depth of about 4 inches using a 12-ton roller, and subsequently following the roller picking with hand picking, as 1.6 cents per square yard, 2,400 square yards being loosened per ten-hour day. The cost was made up as follows:

	Cents Per Sq. Yd.
Picking with roller at $1.00 per hour	0.4
Picking by hand at $.20 per hour	1.2
Total	1.6

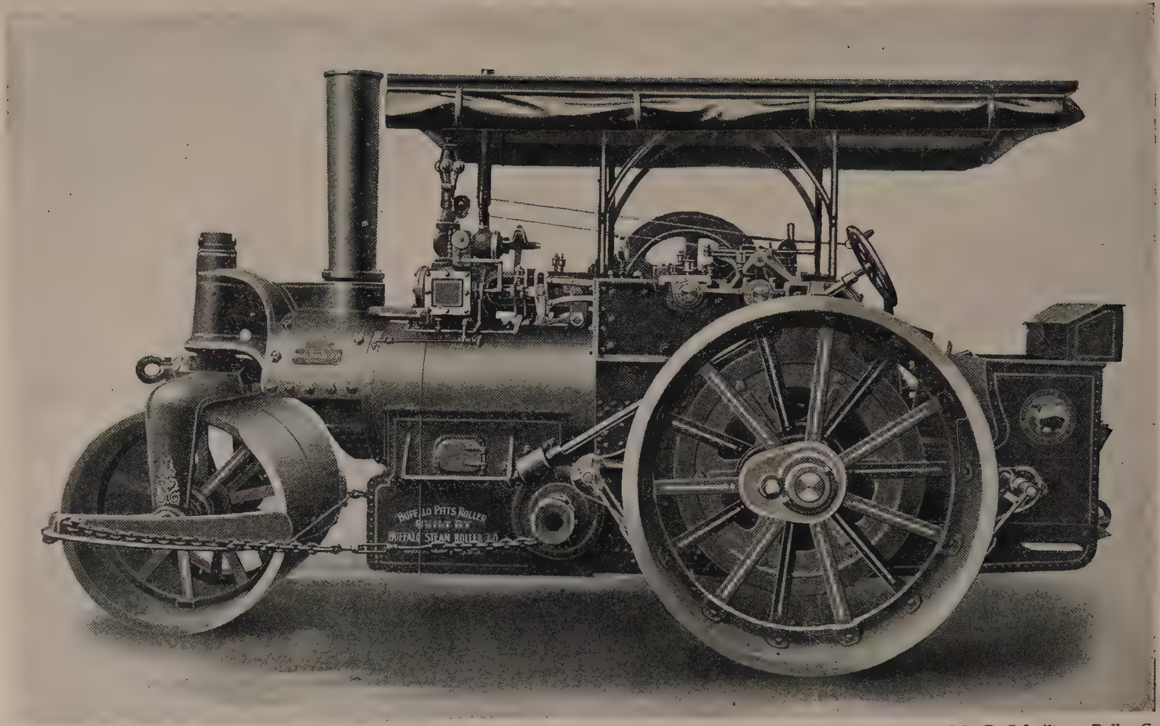
The cost of loosening sandstone macadam by the same author was as follows: It took two ten-hour days to pick up, harrow, and resurface a piece of road 18 feet wide and 1,000 feet long.

	Cents Per Sq. Yd.
Roller at $1.00 per hour	0.5
Harrowing, team and driver, $.30 or	.3
Total	.8

With a scarifier it is possible to loosen on the average of about 2,700 to 3,000 square yards of road a day to a depth of 3 to 4 inches, provided the traffic is such as not to interrupt the work. If the cost for the roller and engineer is $1.00 per hour, scarifier 50 cents per hour, and two laborers 25 cents each per hour, the cost per square yard of work done, at the rates stated above, will vary from 0.66 cent to 0.74 cent.

Implements and Machines. A brief description of the various implements and machines used in the construction and maintenance of broken stone roads follows:

Rollers. The common size of the three-wheel roller varies in weight from 10 to 20 tons. The majority of rollers of this type are run by steam. although there are a few makes which are run

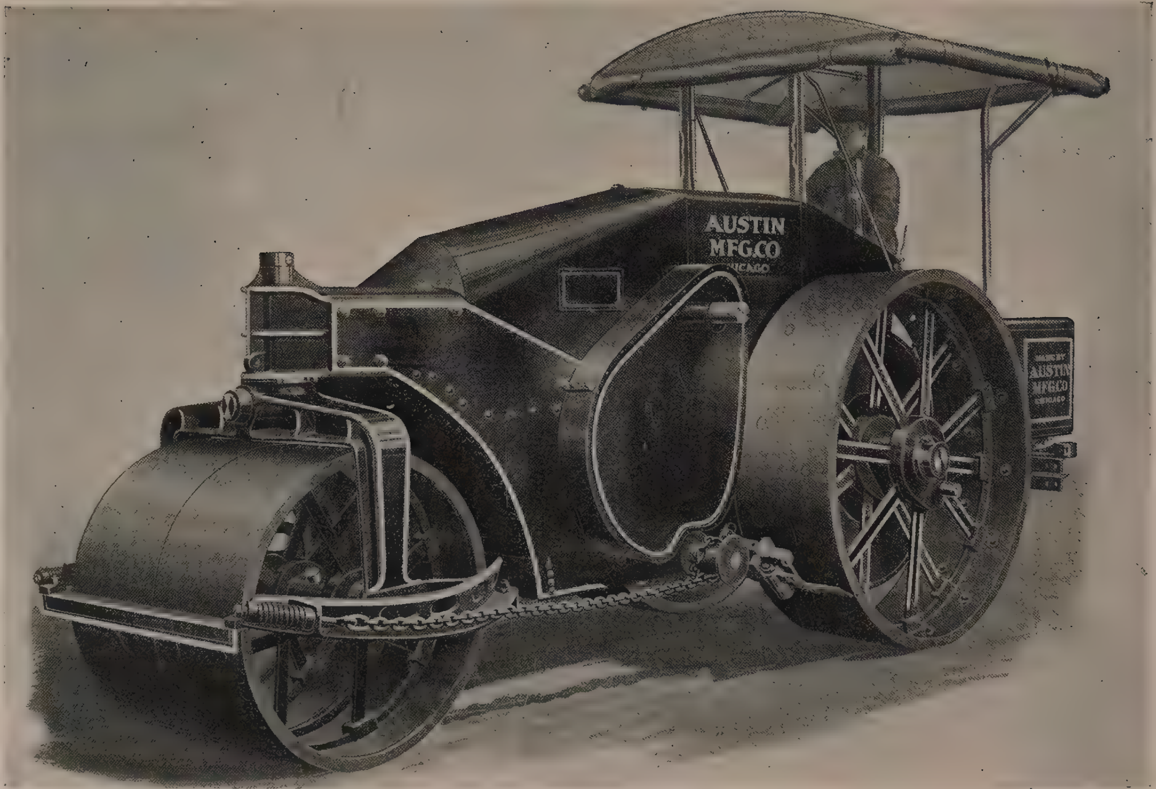


Courtesy of the Buffalo Steam Roller Co

FIG. 90. Three-Wheel Steam Roller.

by gasoline engines. Rollers in Europe, equipped with gasoline engines, have been found to be particularly advantageous, since the roller can be made more compact; no time is lost in waiting to get up steam; the rollers are less noisy; they are generally capable of much more rapid movement; and they are found to be particularly useful in repairing isolated patches on maintenance work. Fig. 90 shows a three-wheel steam roller, and Fig. 91 a three-wheel roller operated by gasoline engine, both of which are manufactured in the United States. Rollers are generally furnished with a high and low speed. The low speed is from 2 to 3 miles per hour and the high speed from 4 to 5. The low speed is used in rolling the subgrade, telford, etc., while the high speed is used in finishing the surface or in traveling from point to point. In rolling sharp curves, the wheel on the outside tends to revolve faster than the wheel on the inside, therefore, if both wheels are locked to the axle, the outer wheel will slip and cut the surface. To prevent this, the lock pin may be taken out on one side, which allows the wheel to run at will or differential gears are provided in some makes so that the wheels automatically accommodate themselves to any difference in speeds. The roller, if well taken care of, should last for twenty years. Three-wheel rollers, varying in weight from 10 to 15 tons, cost from $2,500 to $3,000 f.o.b. at the factory.

Scarifiers. In the United States most of these machines consist of a heavy cast-iron block on two or four wheels which holds a series of steel picks. The blocks weigh about 3 tons and the picks can be adjusted in the block or the block itself arranged so that any depth desired up to 5 or 6 inches can be picked up. The picks are arranged in either a straight line or in two lines which, together, form a V. Most of the scarifiers are so designed that it is not necessary to turn them around. This is accomplished generally by having two sets of picks, one set being used when the machine runs in one direction and the other when in the opposite direction. Scarifiers of this type are towed by a chain hitched to the roller. The arrangement of the picks and the form of the blocks vary, but all of the machines work on the same principle. Figs. 92 and 93 show two American scarifiers



Courtesy of the Austin Mfg. Co.

FIG. 91. Three-Wheel Gasoline Motor Roller

which are typical of the block type. The price of many of the American makes of scarifiers is about $500 f.o.b. factory.

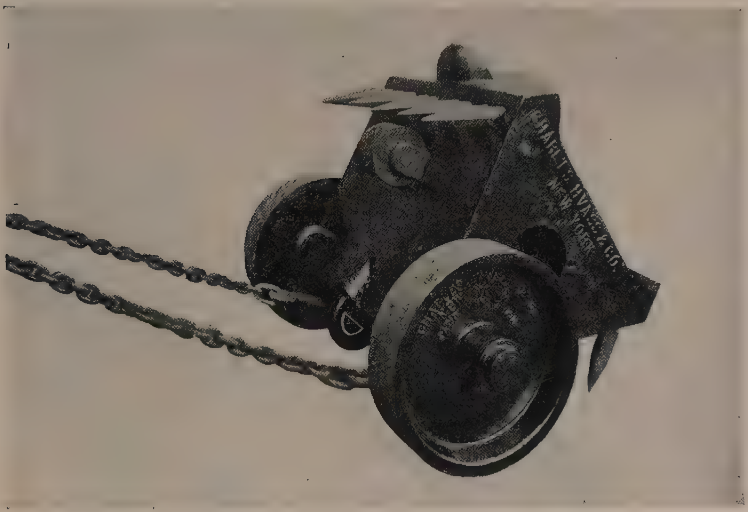
The scarifiers of Europe are of two types, one of which is similar to the block type as illustrated in Fig. 92, while the other is attached to the rear of a three-wheel roller and is a part of the roller, as illustrated in Fig. 94. It consists of a framework supporting a small block in which the picks are inserted. The

FIG. 92. Scarifier.

framework is attached to the rear of the roller so that the pick block is behind one of the driving wheels and the picks are set at such an angle that they are forced into the road by the force of the roller and the weight of the block. The advantages of this type of scarifier are the ease with which it is handled and the saving in time obtained by having the scarifier so attached that it can instantly be put into operation when the roller is traveling in any direction.

Watering-Carts. In the United States the cart used for sprinkling generally consists of a cylindrical tank mounted horizontally on a four-wheel truck. The tank may be made either of wood or of steel. The capacities vary from 350 to 1,000 gallons. The size generally used in constructing broken stone roads

is either 450 or 600 gallons. The wheels are usually made so as to track, and the standard width of tire is from 3 to 4 inches. Many of the manufacturers, however, make one type which is particularly adapted to constructing broken stone roads in which the tires are 6 to 8 inches wide and the wheels overlap. The discharge valves are of two kinds, either horizontal or vertical. The horizontal valve throws water out in a horizontal sheet, while



Courtesy of Charles Hvass and Co.

FIG. 93. Hvass Scarifier.

the vertical valve throws it in a vertical sheet. Fig. 95 illustrates a watering-cart typical of those used in the United States. The cost of a 600-gallon watering-cart is about $350.

Many of the watering-carts used in England and France have a rectangular instead of a cylindrical tank. The tanks are also usually made of steel with capacities ranging from 200 to 400 gallons.

Stone Forks and Rakes. Heavy tine forks will be found useful in handling large-size broken stone, particularly when the stone has been dumped on the ground. The fork can be filled more easily than a shovel, and no dirt will be taken up with

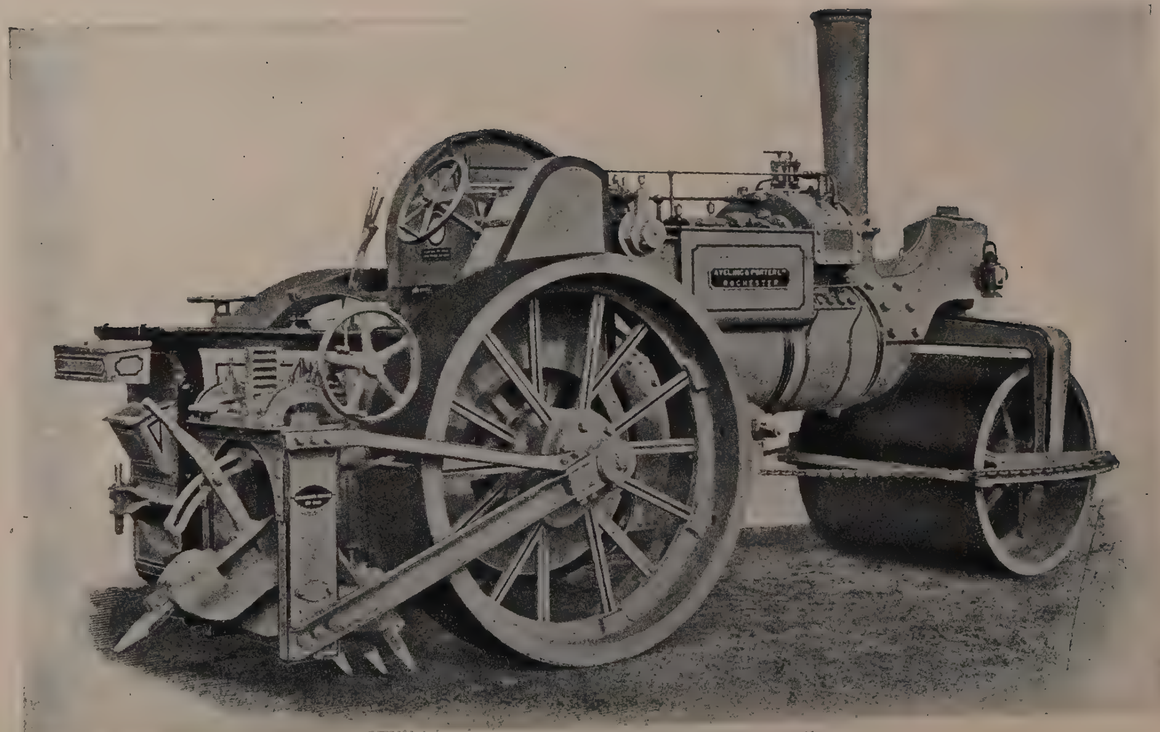


Fig. 94. Morrison Scarifier Attached to Roller.

the stone. A two-handle rake, the handles being arranged on either side of the rake head so that as one man pulls another can push, is used for levelling and spreading stone. Ordinary

Courtesy of the Austin Mfg. Co.

FIG. 95. Watering-Carts.

potato hooks are also useful in pulling down piles of stone or in smoothing out the surface.

Road Scrapers. Stone can be economically spread from heaps by means of almost any of the types of road machine scrapers described in Chapter VII.

CHARACTERISTICS.

An ordinary macadam road, if properly built of the right kind of stone, is a very economical and satisfactory surface for medium horse-drawn vehicle traffic. It affords an excellent foothold, is noiseless, does not offer much resistance to traffic, and is comfortable to use. In dry weather, however, a macadam surface is extremely dusty unless the surface is treated with a palliative or coated with bituminous material.

CHAPTER X

BITUMINOUS MATERIALS

Before considering the details of the treatment of surfaces rendered dustless by the application of palliatives and the construction and maintenance of bituminous surfaces, bituminous pavements and block pavements in connection with which bituminous fillers are employed, the sources, characteristics, and methods of determination of the physical and chemical properties of bituminous materials should be understood. The specific limitations of properties and typical specifications covering bituminous materials will be covered in the various chapters devoted to the above types of construction. As the standard method of distillation adopted by the American Railway Engineering and Maintenance of Way Association to be employed in the analysis of the oil used in the treatment of wood block has usually been adopted in specifications covering wood block pavement, but has not been generally referred to in other specifications including the distillation test, the method of the Association is described in Chapter XVI rather than in this general chapter on the subject of bituminous materials.

NOMENCLATURE *

Under this heading will be included definitions adopted by the American Society for Testing Materials, and those proposed by either the Special Committee on "Bituminous Materials for Road Construction" of the American Society of Civil Engineers,

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* The subject of nomenclature is introduced at this point in order that the general relationship of materials and properties may be understood before a detailed consideration of each is attempted and likewise that the definitions may be readily accessible for consultation during the perusal of this chapter.

by the United States Reporters to the Third International Road Congress, London, 1913, on Communication 10, "Terminology Adopted or to be Adopted in Each Country Relating to Road Construction and Maintenance," by Prévost Hubbard, Assoc. Am. Soc. C. E., or by the authors.

Bituminous Materials and Their Properties. Key. Definitions adopted in 1912 by the American Society for Testing Materials are followed by a †; those proposed by the United States Reporters to the Third International Road Congress are followed by a ‡; and those proposed by Prévost Hubbard in 1910 by a §.

General and Unclassified Definitions.

Acid Sludge is a mixture of sulphonated hydrocarbons resulting from the treatment of bitumens with sulphuric acid.§

Bitumens are mixtures of native or pyrogenous hydrocarbons and their non-metallic derivatives, which may be gases, liquids, viscous liquids, or solids and which are soluble in carbon disulphide.†

Bituminous, containing bitumen or constituting a source of bitumen.†

Cut-Back Products are petroleum or tar residuums which have been fluxed with distillates.‡

Emulsions are oily substances made miscible with water through the action of a saponifying agent or soap.§

Fixed Carbon is the organic matter of the residual coke obtained upon burning hydrocarbon products in a covered vessel in the absence of free oxygen.†

Fluxes are fluid oils and tars which are incorporated with asphalts and semisolid or solid oil and tar residuums for the purpose of reducing their consistency.§

Asphalts and Petroleums and Properties Thereof.

Asphalts are solid or semisolid native bitumens, solid or semisolid bitumens obtained by refining petroleums, or solid or semisolid bitumens which are combinations of the bitumens mentioned with petroleums, or derivatives thereof, which melt upon the application of heat and which consist of a mixture of hydrocarbons and their derivatives of complex structure, largely cyclic and bridge compounds.‡

Asphaltenes are the components of bitumen in petroleums, petroleum products, malthas, asphalt cements, and solid native bitumens, which are soluble in carbon disulphide but insoluble in paraffine naphthas.‡

Asphaltic Petroleums are petroleums which yield asphalts upon reduction.

Asphalt Cement consists of asphalt, pure or mixed with foreign matter, which may or may not be fluxed with petroleum residuums.

Blown Petroleums are semisolid or solid products produced primarily by the action of air upon originally fluid native bitumens which are heated during the blowing process.‡

Carbenes are those components of the bitumen in petroleum, petroleum products, malthas, asphalt cements, and solid native bitumens, which are soluble in carbon disulphide but insoluble in carbon tetrachloride.‡

Cracked Oil is petroleum residuum which has been overheated in the process of manufacture.§

Malthas are very viscous native bitumens.

Native Bitumens are mixtures of hydrocarbons occurring in nature, which may be gases, liquids, viscous liquids, or solids which are soluble in carbon disulphide.

Residual Petroleums or Residual Oils are heavy viscous residues produced by the evaporation or distillation of crude petroleums until at least all of the burning oils have been removed.§

Rock Asphalt is a term applied to a great variety of sandstones and limestones more or less impregnated with malthas.§

Tars and Properties Thereof.

Tars are bitumens which yield pitches upon fractional distillation and which are produced as distillates by the destructive distillation of bitumens, pyrobitumens, or organic materials.‡

Coal Tar is the mixture of hydrocarbon distillates, mostly unsaturated ring compounds, produced in the destructive distillation of coal.‡

Coke-oven Tar is coal tar produced in by-product coke ovens in the manufacture of coke from bituminous coal.‡

Dead Oils are oils with a density greater than water which are distilled from tars.†

Dehydrated Tars are tars from which all water has been removed.‡

Free Carbon in Tars is organic matter which is insoluble in carbon disulphide.†

Gas-House Coal Tar is coal tar produced in gas-house retorts in the manufacture of illuminating gas from coal.‡

High-Carbon Tars are tars containing 20 percent or more of free carbon.§

Low-Carbon Tars are tars containing less than 10 percent of free carbon.§

Medium-Carbon Tars are tars containing between 10 percent and 20 percent of free carbon.

Oil Gas Tars are tars produced by cracking oil vapors at high temperatures in the manufacture of oil gas.‡

Pitches are solid residues produced in the evaporation or distillation of bitumens, the term being usually applied to residues obtained from tars.‡

Refined Tar is a tar freed from water by evaporation or distillation which is continued until the residue is of desired consistency; or a product produced by fluxing tar residuum with a tar distillate.‡

Water-Gas Tars are tars produced by cracking oil vapors at high temperatures in the manufacture of carbureted water gas.‡

USE OF BITUMINOUS MATERIALS. **Key.** Definitions proposed by the Special Committee of the American Society of Civil Engineers are followed by a †; those proposed by the United States Reporters to the Third International Road Congress by a ‡.

Asphalt Block Pavements are those having a wearing surface of blocks of asphaltic concrete.‡

Binders are foreign materials introduced into the mineral portion of the wearing surface which increase the ability of the latter to retain its integrity under stress as well as perhaps to aid in its first construction. Cement, bituminous materials, clay, sulphite liquor, etc., are examples. The term is used also to

a considerable extent for designating the course in a sheet asphalt pavement frequently used between the concrete foundation and the sheet asphalt mixture of graded sand and asphalt cement.‡

Bituminous Concrete Pavements are those having a wearing surface composed of stone, gravel, sand, shell or slag, or combinations thereof and bituminous materials incorporated together by mixing methods.†

Bituminous Gravel Pavements are those composed of gravel and bituminous materials incorporated together by penetration methods.

Bituminous Macadam Pavements are those consisting of broken stone and bituminous materials incorporated together by penetration methods.

Bituminous Sand Pavements are those composed of sand and bituminous materials incorporated together by penetration methods.

Bituminous Shell Pavements are those composed of shell and bituminous materials incorporated together by penetration methods.

Bituminous Slag Pavements are those composed of slag and bituminous materials incorporated together by penetration methods.

Bituminous Surfaces consist of superficial coats of bituminous materials with or without the addition of stone or slag chips, gravel, sand, or material of similar character.†

Carpets are bituminous surfaces of appreciable thickness, generally formed on the top of a road or pavement by the application of one or more coats of bituminous material with gravel, sand, or stone chips added.‡

Dust Layers are materials applied to a road surface for temporarily preventing the formation or dispersion under travel of distributable dust.‡

Flush Coats are superficial applications, during construction, of bituminous material to bituminous pavements in place and considered complete in their construction as only to need these coatings for their finishing.‡

Penetration Methods are processes of constructing bitumi-

nous macadam pavements by pouring or grouting the bituminous materials into the upper course of the road metal before the binding of the latter has been completed.‡

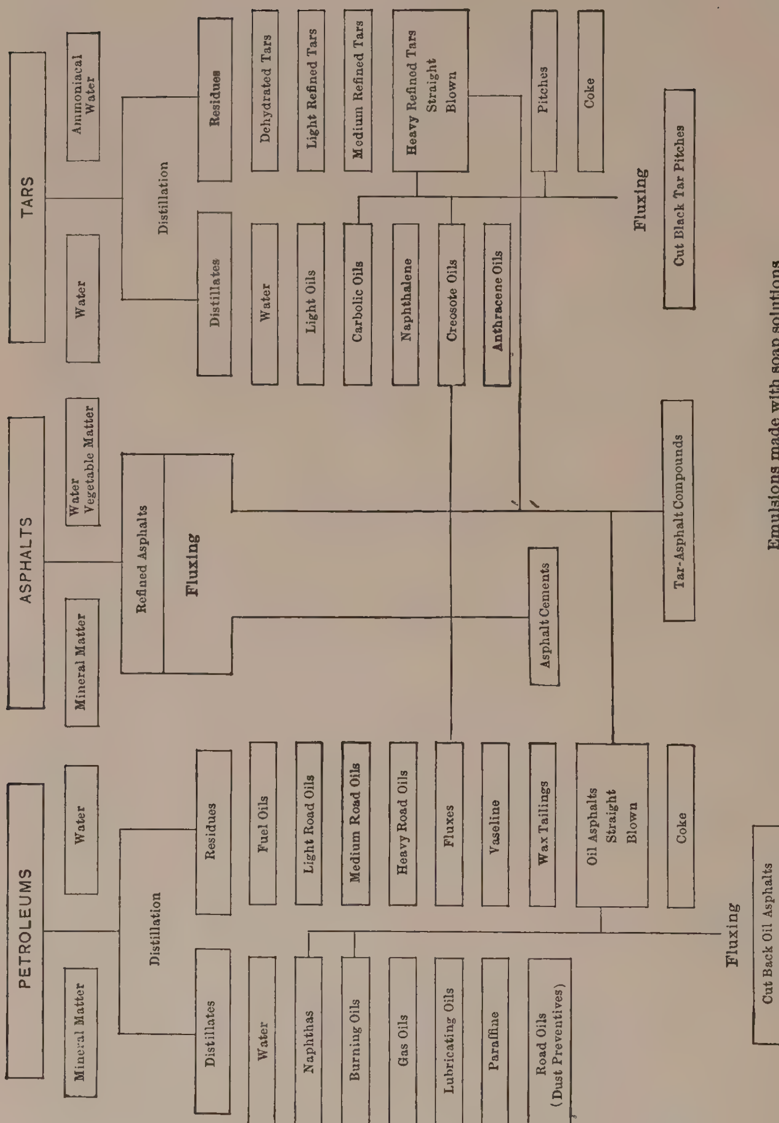
Rock Asphalt Pavements are those having a wearing surface composed of broken or pulverized rock asphalt with or without the addition of bituminous materials.‡

Setting Up refers to the relatively quick change taking place in the bituminous material after its application to a road surface, indicated by its hardening after cooling and exposure to atmospheric and travel conditions, as opposed to the slower changes later occurring gradually and almost imperceptibly.‡

Sheet Asphalt Pavements are those having a wearing surface composed of sand of predetermined grading, fine material and asphalt cement incorporated together by mixing methods.‡

The Special Committee of the American Society of Civil Engineers on "Bituminous Materials for Road Construction," in its 1913 Report, called attention to the misuse of two of the terms mentioned above. "Your Committee, recognizing an unfortunate tendency to use as the generic expression the terms 'bituminous material' and 'bitumen' synonymously, recommends that the term 'bituminous material' be used as a generic expression when referring to road and paving materials containing bitumen and that the term 'bitumen' be used in a restricted sense as covered by the following definition adopted by the American Society for Testing Materials. 'Bitumens are mixtures of native or pyrogenous hydrocarbons and their non-metallic derivatives, which may be gases, liquids, viscous liquids, or solids, and which are soluble in carbon disulphide.' An illustration of ambiguity in the use of the two terms may be found in some descriptions of bituminous pavements, where a bituminous cement, only 75 percent soluble in carbon disulphide, was used. In the general description of these pavements, the word 'bitumen' was used to refer to the material as a whole, while in giving the analysis of the mix, the word 'bitumen' was used to refer only to that portion of the cement soluble in carbon disulphide."

TABLE No. 12


TARS
Ammoniacal Water
Water
Distillation
Residues
Distillates
Dehydrated Tars
Light Refined Tars
Medium Refined Tars
Heavy Refined Tars Straight Blown
Pitches
Coke
Water
Light Oils
Carbolic Oils
Naphthalene
Creosote Oils
Anthracene Oils
Fluxing
Cut Black Tar Pitches
ASPHALTS
Water Vegetable Matter
Mineral Matter
Refined Asphalts
Fluxing
Asphalt Cements
Tar-Asphalt Compounds
Emulsions made with soap solutions
PETROLEUMS
Water
Mineral Matter
Distillation
Residues
Distillates
Fuel Oils
Light Road Oils
Medium Road Oils
Heavy Road Oils
Fluxes
Vaseline
Wax Tailings
Oil Asphalts Straight Blown
Coke
Water
Naphthas
Burning Oils
Gas Oils
Lubricating Oils
Paraffine
Road Oils (Dust Preventives)
Fluxing
Cut Back Oil Asphalts

Sources, Mining and Manufacture

The bituminous materials which are used in the construction and maintenance of roads and pavements will be considered under the various heads of the following general classification: Asphaltic Petroleums; Asphalts; Rock Asphalts; Coal Tars; Coke Oven Tars; and Water Gas Tars. Prévost Hubbard, Assoc. Am. Soc. C. E., has compiled a Table, No. 12,* showing graphically the interrelationship between the principal types of bituminous materials used in highway engineering. In explanation of Hubbard's diagram the following is quoted. "It will be noted that the crude materials are divided into three general classes—petroleums, asphalts, and tars—which are all subjected to the process of sedimentation before further use, in order to remove water and other impurities in so far as possible. Distillation is the second process involved in the preparations of petroleum and tar products, and in each case two classes of products are formed—distillates and residues."

Asphaltic Petroleums. The general conditions existing in 1912 relative to the attempted differentiation of the types of petroleums used in the road and paving industry, the cccurrence and production of asphaltic petroleums in America and the rates of production have been summarized by Francis P. Smith,† M. Am. Soc. C. E.

Nomenclature. "In the United States petroleums considered from the asphalt-producing standpoint were first divided into two classes: viz., paraffine and asphaltic. Broadly speaking, Pennsylvania petroleums were considered typical of the paraffine type and California petroleums of the asphaltic type. It is probably true, as Mayberry asserts, that all petroleums have the same chemical composition, the varying proportions of the different ingredients resulting in the different types found in different localities, and this is further shown by the fact that

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* See *Journal of the Franklin Institute*, April, 1912.

† See 1912–1913 Lecture on "Mining and Refining of Asphaltic Oils" before Graduate Students in Highway Engineering at Columbia University.

very satisfactory grades of paving asphalts have been obtained from the sludge produced in refining distillates from paraffine oils. When this classification was first used oil was not obtained in the United States in as many places and of as many different kinds as at present and the difference between the two types was very marked. As different fields were opened, petroleums were found that exhibited some of the characteristics that had heretofore been found exclusively in the paraffine type of oils combined with other characteristics that had been considered exclusive properties of the asphaltic oils. Such oils were termed semi-asphaltic oils and the dividing lines between the three types thus established became less and less clearly marked. The manufacturers of paving asphalts tended to add to the confusion by classifying oils which were really semi-asphaltic as asphaltic, and oils which were not even semi-asphaltic as semi-asphaltic, until at the present time the distinction between the three classes is very badly muddled.

Occurrence of Asphaltic Petroleum. "The strata in which the petroleum is actually found differs in character in different localities from a loose sand to a coherent rock. The thickness of the oil-bearing strata also varies greatly, as does the depth at which it is found. Surface outcrops and seepages exist in many places, while, on the other hand, wells are frequently drilled to a depth of 4,000 feet or over. At the present time asphalts and asphaltic products, including road binders, are chiefly made from the oils produced in the following fields: California, Texas (Gulf Coast and Louisiana), Southern Illinois, and Mexico.

Rate of Production. 1912. "The present total oil production from these fields is approximately as follows:

California........	200,000 bbls. per day	60,000,000	per year
Texas...........	25,000 " " "	7,500,000	" "
Southern Illinois..	50,000 " " "	15,000,000	" "
Mexico..........	100,000 " " "	30,000,000	" "

In addition to the above, a small amount of asphaltic oil has been produced in Trinidad, some of which has been used in manufacturing road binders, etc. The present total output of this field is probably not in excess of 200,000 barrels of oil per annum."

Asphalts and Rock Asphalts. In order that the multiplicity of sources of asphalt may be emphasized, the definitions of asphalt as included in the communication of the United States Reporters to the Third International Road Congress, London, 1913, is here repeated.

Asphalts are solid or semisolid native bitumens, solid or semisolid bitumens obtained by refining petroleums, or solid or semisolid bitumens which are combinations of the bitumens mentioned with petroleums, or derivatives thereof, which melt upon the application of heat and which consist of a mixture of hydrocarbons and their derivatives of complex structure, largely cyclic and bridge compounds.

Rock Asphalt is a term applied to a great variety of sandstones and limestones more or less impregnated with malthas.

The Trinidad and Bermudez asphalt cements contain asphalt as defined under the first group, that is, "asphalts are solid or semisolid native bitumens, etc."

The asphalts obtained by refining such asphaltic oils as are obtained from the fields of California, Texas, Southern Illinois, and Mexico come within the second group, that is, "asphalts are solid or semisolid native bitumens obtained by refining petroleums, etc."

The asphalts made from a combination of refined asphaltic oil and Gilsonite, a solid native bitumen, are covered by the third group to which reference has been made, namely, "asphalts are solid or semisolid bitumens which are combinations of the bitumens mentioned with petroleums or derivatives thereof, etc."

The rock asphalts in common use in Europe are composed of limestones and sandstones impregnated with 7 to 14 percent of asphalt. The principal sources are at Ain, Autun, Aumance, Gard, Haute-Savoie, Levagny, Mons, Puy-du-Dome, and Seyssel in France; at Val de Travers in Neuchatel, Switzerland; at Ragusa, Syracuse, Mazzarelli, and Catania in Sicily; at Lobsann, Alsace; and at Limmer, Hanover, Germany. With reference to the mining of rock asphalt in the United States, Dr. Day states that during 1911 "the production of bituminous rock showed a marked decrease, owing chiefly to the cost of transportation

for material containing a relatively small quantity of asphalt." The rock asphalts of the United States are found principally in California, Kentucky, Oklahoma, and Utah.

Production. According to Dr. David T. Day, Director of the United States Bureau of Mines, Table No. 13 gives the production in the United States for 1910 and 1911 by varieties in short tons.

TABLE No. 13.

FROM "MINERAL SOURCES OF THE UNITED STATES, 1911."

Variety	1910 Quantity	1910 Value	1911 Quantity	1911 Value
Bituminous rock	64,554	$400,557	51,328	$161,219
Refined bitumen	5,018	85,931	9,305	317,722
Maltha	1,252	12,742	8,574	125,966
Wurtzilite (elaterite)	.....	....	610	30,500
Gilsonite	29,832	372,900	30,236	486,114
Grahamite	.....	....	5,000	15,000
Ozokerite and tabbyite	.....	....	.....	....
Oil asphalt	159,424	2,207,937	234,951	2,684,230
Total	260,080	$3,080,067	360,004	$3,820,751

Table No. 14 gives the production in 1911, by varieties and by States, in short tons. Table No. 15 gives the production of all the varieties listed in Table No. 14 in the principal producing countries of the world, 1902–1909, in short tons.

In Table No. 16 is given a synopsis of the chief sources of asphalt in foreign countries. The remarks quoted are excerpts from the published table.

TABLE No. 16.

FROM "MINERAL SOURCES OF THE UNITED STATES, 1911."

Country	Kind	Remarks
Cuba:	Glance pitch.	Asphalt has been reported in every Province.
Pinar del Rio	Asphaltic sandstone	Formerly mined near Bahia Honda.
Habana	Soft asphalt	More than a dozen openings, some large, between Habana and Mariel. All the present production comes from these deposits.
Matanzas	Hard and soft	Hard asphalt was mined for years from the bottom of Cardenas Harbor by Sr. Torrentegui and sold for

TABLE No. 14.

FROM "MINERAL SOURCES OF THE UNITED STATES, 1911."

Variety	California		Utah		Oklahoma*		Texas		Total	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
Bituminous rock	27,507	$89,264	.....	......	23,821	$71,955	.....	......	51,328	$161,219
Refined bitumen	15,589	179,646	.....	......	.....	......	13,800	$128,000	29,305	317,722
Maltha	8,574	125,966	.....	......	.....	......	.....	......	8,574	125,966
Uintaite (Gilsonite)	......	....	30,236	$486,114	.....	......	.....	......	30,236	486,114
Wurtzilite (elaterite) and tabbyite	......	....	610	30,500	.....	......	.....	......	610	30,500
Grahamite	......	....	.....	......	5,000	15,000	.....	......	5,000	15,000
Oil asphalt	139,275	1,709,545	.....	......	52,650	315,900	43,026	658,785	234,951	2,684,230
Total	190,945	$2,104,421	30,846	$516,614	82,387	$412,931	55,826	$786,785	360,004	$3,820,751

* Includes Illinois and Kentucky.

TABLE No. 15.

FROM "MINERAL SOURCES OF THE UNITED STATES, 1911."

Year	United States	Trinidad	Germany	France	Italy	Spain	Austria-Hungary	Russia	Venezuela
1902	105,458	178,230	97,415	284,719	70,619	6,946	4,047	13,624	11,872
1903	101,255	204,880	96,401	267,859	98,865	6,918	2,715	28,281	16,057
1904	108,572	152,392	101,121	250,222	123,347	4,146	4,029	95	14,910
1905	115,267	114,845	113,513	211,043	117,929	7,135	8,257	23,659	33,803
1906	138,059	150,373	129,388	216,405	144,802	8,587	10,633	12,517	22,128
1907	223,861	171,271	139,567	195,136	178,127	9,057	11,335	14,116	37,637
1908	198,382	143,552	98,088	188,616	148,433	13,635	12,239	24,961	31,539
1909	228,655	159,416	85,446	186,298	123,361	5,822	11,179	.....	37,292

		varnish. Soft asphalt was mined at the mouth of Rio de Palma. Much soft material is found on the Hamel properties, near Sabanilla de la Palma.
Santa Clara	Hard	At Placetas del Sur perpendicular veins of hard varnish pitch have been opened. Specimens of soft asphalt have been obtained in the same neighborhood.
Camaguey	Hard	On the western edge of the Province considerable deposits have been opened and mined and hauled on mule back to Caibarien, on the north coast.
	Soft	Near Minas, a station between Camaguey and Nuevitas, a pit 37 feet deep shows soft asphalt seeping into it. Hardened material is found near the surface in pieces in the soil.
Santiago de Cuba.	Hard	Six miles south of Puerto Padre; not developed.
Mexico	Hard and soft	In Vera Cruz and Tamaulipas asphalt seepages, usually soft, are very numerous at the contact of the limestones with eruptive masses. Occasionally the amount of asphalt is very great, especially near Tuxpam.
Trinidad	Soft; mixed with much clay and water.	Impure mixture of soft asphalt, water, and clay, having somewhat the nature of petroleum emulsions.
Venezuela (Bermudez).	Soft; purer than Trinidad.	Mined by hand labor and hauled in mine cars to river lighters and transferred again to steamers for export, chiefly to the United States.
Barbados	Glance pitch, used for varnish — called "Manjak."	It occurs on the east side of the island in veins with a north-northeast strike and varying dip.
Argentina	Soft	Occurs, in connection with heavy oils, near Comodoro Rivadiva. Not yet productive.
France	Bituminous limestone.	The limestones and schists, containing usually 7 to 14 percent of asphalt, are found at Autun, in the Department of Saône-et-Loire; at Aumance, in Allier; and in Ain

		Gard, Puy-du-Dôme, and Haute-Savoie. The asphalt has been mined since 1838, and has been largely used in paving the streets of Paris. It has also been exported in large quantities.
Switzerland	Bituminous limestone.	In 1912 the 200-year jubilee will be celebrated of the discovery of asphaltic limestone. Worked at Val de Travers, Neuchatel.
Italy	Bituminous limestone.	In Sicily, at Ragusa, Syracuse, Mazzarelli, and Catania.
Germany	Asphaltic limestones and sandstones.	At Lobsann, Alsace. Operated in a primitive way for 75 years. Veins 3 to 30 feet thick.
Greece	Asphaltic limestone.	Near Marathonopolis; 15 to 25 per cent of asphaltic oil.
Syria	Hard varnish pitch.	Principal mine is at Hasbeya, near the headwaters of the Jordan; also around the Dead Sea, in Latakia Mountains, and in southern Palestine, near Beersheba.
Russia	Hard and asphaltic sandstones.	Near Syzran and Samara, and very commonly in the Caucasus; also on Tcheleken Island, in the Caspian Sea. Ozokerite is also found in the last place.
Turkey	Hard	Worked chiefly at Selenitza, in Albania; also occurs in many other localities, particularly near Nasarieh, Busreh Province.
Japan	Hard	In Echigo, associated with oil seepages.
Galicia	Ozokerite	Most of the ozokerite comes from Boryslaw, with smaller quantities from Dzwiniacz, Starunia, and Truskamiec. Described in "Der Erdwachsbergbau in Boryslaw," by J. Muck (Julius Springer, Berlin, 1903). The ozokerite occurs partly in fairly pure masses, and also disseminated through the Miocene clays in which it is found. The masses are purified by melting. The clay containing ozokerite is heated in water until the melted wax rises to the surface.

Russia..........	Ozokerite..........	Large quantities are reported on Tcheleken Island, in the Caspian Sea.

Francis P. Smith, M. Am. Soc. C. E., states* that the present production in the United States of asphalt and road binders, etc., from oils from the following fields is approximately as follows:

California..........	150,000	tons,	representing	3,000,000	bbls. oil
Mexico	40,000	"	"	800,000	" "
Texas..............	25,000	"	"	500,000	" "
Southern Illinois....	60,000	"	"	1,200,000	" "
	275,000	"	"	5,500,000	" "

Mining and Manufacture. As illustrative of methods of mining and manufacture which are employed in the asphalt industry there are given abstracts of papers by Messrs. Pullar and Richardson.

Trinidad and Bermudez Asphalts. The source of the bitumen used, the mining methods employed, and the process of manufacture of Trinidad and Bermudez Asphalt Cement are described as follows by Clifford Richardson,† M. Am. Soc. C. E.

"Of the deposits of asphalt which are of great industrial importance there are two which have attracted world-wide attention, the so-called Trinidad Pitch Lake and the Bermudez Pitch Lake, the name lake being applied to them very naturally, as they consist of a great expanse of more or less mobile character, covering many acres, and resembling in many ways a similar expanse of water. The Island of Trinidad lies off the north coast of South America, between 10 degrees and 11 degrees of latitude and 61 degrees and 62 degrees longitude.

"The main deposit is a body of pitch known as the pitch lake, situated at the highest part of the point. Between this and the sea, and more especially toward La Brea, are other deposits,

* See 1912–1913 Lecture on "The Mining and Refining of Asphaltic Oils," before the Graduate Students in Highway Engineering at Columbia University.

† See 1911–1912 Lecture on "Trinidad and Bermudez Asphalts," before the Graduate Students in Highway Engineering, at Columbia University.

covered more or less and mixed with soil. The pitch from these sources is classified as 'lake pitch' and 'land pitch.' By far the largest amount of pitch is found apparently in the pitch lake, a nearly circular area of 114.67 acres, 138 feet above sea level. In past times the pitch very probably continued to collect until it overflowed the rim of the crater, particularly toward the north, and thus perhaps became the source of some or all of the land pitch deposits now found between the lake and the sea. As to the depth of the lake, borings made in 1894 at the center were carried to a depth of 135 feet, by means of a wash drill, the entire distance being through asphalt of the same character as that at the surface.

"The material forming this deposit is an emulsion of water, gas, bitumen, and mineral matter, the latter consisting largely of fine sand and a lesser amount of clay. It is in constant motion, owing to the evolution of gas, and for this reason whenever a hole is dug in the surface, whether deep or shallow, it rapidly fills up, and the surface resumes its original level after a short time. While sufficiently soft to accommodate itself to any change of level and to slow movement, it can be readily flaked out with picks, in large conchoidal masses weighing from 50 to 75 pounds. It is honeycombed with gas cavities, and resembles in appearance the structure of a Swiss cheese.

"It consists of, according to the most refined methods of analysis, from whatever part of the deposit it is taken:

	Crude Percent	Dry Percent
Water and gas, volatilized at 100 degrees C.	29.0	
Bitumen soluble in cold carbon disulphide	39.0	56.5
Bitumen retained by mineral matter	0.3	0.3
Mineral matter, on ignition with tricalcium-phosphate	27.2	38.5
Water of hydration in clay and silicate	3.3	4.2
	98.8	99.5

"In what has been said hitherto reference was had to the asphalt taken from the lake deposit itself. As has been mentioned, there are deposits of bitumen between the lake and the sea, and the material taken therefrom is known as land pitch.

It has been subject to atmospheric weathering and by contact with the soil for years, as a result of which its physical properties are inferior to those possessed by the lake deposit. The greater the distance from the lake at which the land pitch is found, the more it shows signs of age and weathering and the more inferior it is.

"About 30 miles in an air line from the coast of Venezuela the asphalt deposit, known as the Bermudez pitch lake, is found at the point where a northern range of foothills comes down to the swamp. The level of the surface of the deposit does not vary more than two feet and is largely the same as that of the surrounding swamps. In the rainy season it is mostly flooded and at all times very wet, so that any excavation will fill up with water. These conditions make it difficult to get about upon it or to excavate pitch easily. It is readily seen that this deposit is a very different one from that in the pitch lake of Trinidad. It seems to be in fact merely an overflow of soft pitch from several springs, over this large expense of savanna, and one which has not the depth or uniformity of that at Trinidad. At different points there is at most a depth of 7 feet of material, while the deepest part of the soft maltha is only 9 feet and the average of pitch below the soil and coke only 4 feet. At points there is not more than 2 feet of pitch, and in the morichales or palm groves it is often 5 feet below the surface. At several points scattered over the surface are areas of soft pitch, or pitch that is just exuding from springs. The largest area is about 7 acres in extent and of irregular shape. This has little or no vegetation upon it, and from the constant evolution of fresh pitch is somewhat raised above the level of the rest of the deposit. This soft asphalt has become hardened at the edges, but when exposed to the sun is too soft to walk upon. The material is of the nature of a maltha and it is evidently the source of all the asphalt in the lake, from these exudations the pitch having spread in every direction, so that no great depth of pitch is found even at this point.

"An examination of a series of samples collected in 1894 shows that the asphalt from the Bermudez deposit may vary

very largely in the amount of water which it contains, from 11 to 46 percent. None of it, however, is present in the form in which it occurs in Trinidad asphalt. It is not emulsified with the bitumen, but is all adventitious surface water. The percentage of oils which it volatilizes at about 400 degrees Fahrenheit varies from 16 to 6 percent, consequently the consistency is far from uniform. The material carefully selected for use industrially is fairly constant in character, however, and when carefully refined has the following approximate composition:

Specific gravity, 77/77 degrees Fahrenheit, original substance dry	1.082	
Penetration at 77 degrees Fahrenheit, 5 seconds, 100 grams, No. 2 needle	3.0 mm.	
Loss 20 grams 325 degrees Fahrenheit, 7 hours, 2¼ inch dish	2.9	percent
Bitumen soluble in CS_2 air temperature (70 degrees Fahrenheit)	94.6	"
Difference	1.5	"
Inorganic or mineral matter	3.9	"
	100.0	"
Bitumen soluble 88 degree naphtha, air temperature (70 degrees Fahrenheit)	67.3	"
Bitumen yields on ignition: Residual coke	12.9	" "

Gilsonite Asphalt. The method of refining in which air is blown through the oil and the process of manufacture of asphalt using the solid native bitumen Gilsonite formed the basis of a paper * by H. B. Pullar, Assoc. Am. Soc. C. E.

"The essential requirement to get a first-class blown product is naturally the raw oil itself. After a careful study of the oil and when a satisfactory grade has been obtained, it is put into semi-open stills or kettles, holding between 2,000 and 5,000 gallons. These stills are fully equipped with steam coils and the temperature controlled by means of superheated steam, so as to prevent any further cracking of the oil and so that the temperature may be raised very slowly as desired and to a uni-

* See "Blown Oils and Their Manipulation," 1911 Annual Meeting, American Association for the Advancement of Science.

form point. They are fully equipped with perforated pipes at the bottom, through which is forced the injection of air. The oil is run into the stills at a temperature of about 160 degrees Fahrenheit, at which temperature more air is injected. The increased injection of air at this point causes internal heat and it may be necessary to lower the temperature of superheated steam. By the combination of internal and external heat, the temperature is then gradually increased until it reaches approximately 425 degrees Fahrenheit, at which point it is kept uniform. A copious supply of air is then injected through the oil and the treatment continued for ten, twenty, or forty hours, depending upon results required for the different products.

"In order to produce high-grade bituminous materials for paving, water-proofing, insulation, etc., it is necessary to add some desirable basic material which readily combines with the blown oil to give it more density and strengthen the good qualities which the blown oil contains. Gilsonite, a pure native bitumen, readily combines with the blown oil."

Tars. The methods of manufacture and certain characteristics of coal gas tars, coke oven tars, and water gas tars should be given consideration by the engineer and chemist, since the information is of value in the writing of specifications covering the properties and use of such bituminous materials. There are also wood tars, resulting from the destructive distillation of wood in the manufacture of pyroligneous acid and wood alcohol, and oil tars, obtained by the destructive distillation of certain petroleums in the manufacture of oil gas.

Coal Gas Tar. During the past decade especially, attention has been devoted to the production of coal tar and the methods of refining to obtain tars for use in the construction of road surfaces and pavements. The following abstracts from a lecture * delivered by Philip P. Sharples, Chief Chemist, Barrett Manufacturing Company, cover the essentials relative to the

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* See 1912–1913 Lecture on "The Manufacture of Refined Coal Tar," before the Graduate Students in Highway Engineering at Columbia University.

manufacture of crude coal tar and the methods of refining employed.

"In classifying coal tars for use in road work it is customary to group them, in accordance with the method of manufacture, into gas house tars and coke oven tars. These groupings are made wholly from the method of manufacture, but within limits the chemical characteristics of the tars fall well within the two groups. There will be found, however, a gradation in differences, in which the tars of one class overlap in places the tars of the other class. The following table gives roughly the characteristic differences in the two tars:

	Gas tar	Coke oven tar	
Water	2.9	2.2	Percent
Light oil up to 200 degrees Centigrade	4.0	3.4	"
Benzol for aniline	0.92	1.1	"
Solvent naphtha	0.20	0.32	"
Creosote oil	8.6	14.5	"
Crude naphthalene	7.4	6.7	"
Anthracene oil	17.4	27.3	"
Pure anthracene oil	0.60	0.70	"
Pitch	58.4	44.3	"
Carbon	15–25	5–8	"

"The results obtained are from tars made from the same coal in the two ovens. The difference in the two tars, of which the most marked is that in the free carbon content, is due more to differences in temperature in the two processes than to any difference in the methods of making the gas.

Source of Crude Coal Tar. "As gas houses are usually run for the production of the largest possible yield of gas from a ton of coal, the highest possible temperatures are employed, and the tar produced has in consequence usually a maximum amount of free carbon. This, however, is not always so and low carbon tars may be made at gas houses. Very recently there has been installed at a number of gas houses in the United States a new form of retort, differing essentially from the older small horizontal retort. These new retorts are either inclined or vertical, to permit of the handling of the coke by gravity and by mechanical means. The form of the retort leads to low temperatures in the coking

of the coal, and the escape of the tar and gases through comparatively cool passages. The tars resulting from these forms of ovens may show even lower carbons than the coke oven tars. A thorough examination of these tars would probably disclose an even greater preponderance of the lighter oils than in the case of coke oven tar.

"The collection of the tar as it is evolved from the retort is essentially the same in principle in the two types of gas plants. The tar, owing to the high temperature, goes off as a vapor mingled with the gases. Condensed, however, at a comparatively high temperature, the greater part is deposited in the large collecting gas main known as the hydraulic main, where it is trapped and led to the storage tank. Some further part is deposited in the condensers, where the temperature of the gas is brought down by passing over water-cooled surfaces to a workable temperature. Part of the tar, however, is so finely divided mechanically that it is carried on by the stream of the gas through the condensers. The method of removing the last particles of tar from the gas varies greatly in different plants, but usually a system of baffle plates is used which coalesces the particles of tar by impinging them upon the opposed plates. The tar collected in these several places is all conducted to the same storage tank.

Manufacture of Refined Coal Tar. "The first process in refining tar is the removal of the water. The presence of a large amount of water leads to frothing in the still, making the process of distillation extremely slow, and in case the still actually froths over, to the loss of the charge. The most successful method in use at the present time is to pass the tar in thin films, at about the temperature of boiling water, through vacuum chambers. This results in the elimination of a large percentage of water, and also to the driving off of some of the light oils, which are condensed and recovered from the vapors. But it is usually not possible even by this method to reduce the water below 1 percent.

"The stills used in the tar industry are constructed of steel and are of various shapes and sizes. In Europe a vertical still is generally used, as it is claimed that a greater fuel economy results. The size and strength of the still, however, are not easily enlarged,

and this has led to the favoring of the horizontal cylindrical still in the United States. While 2,000 or 3,000 gallons is considered abroad the proper size for a still, in this country stills of 10,000 gallons capacity are standard in the larger plants.

"After the stills are charged with the correct blend of tars to produce the desired results, the fires are started and the mixture heated carefully to about 100 degrees Centigrade. The water, together with the light oils, is driven off. The distillation once started continues to about 220 degrees Centigrade. Then the flow of the liquor becomes less and the temperature is increased until the oil begins to come off freely once more. The oils during the first part of the distillation are accompanied by much water. This is carefully separated from the oil and then the oil run into tanks. It constitutes the crude light oil used for the manufacture of benzol and toluol.

"In the manufacture of the very lightest refined road tars the distillation is carried only to the point where the water is completely off. In England and on the Continent this constitutes the major portion of the refined tar used for road purposes, applicable to surface treatment of a road, especially where a very thin coat is desired. In case the material to be manufactured is to be used for road construction, the firing on the still is continued much longer, and much more of the oil taken off. It is customary in this case, in order that the viscosity of the material may be closely regulated, to subdue the fire before the end point is reached. Then in order to raise the viscosity to the required point, air or steam is blown through the hot tar in the still, to remove further oils and bring the tar to the desired consistency. This 'blowing,' as it is called, becomes much more important as the melting point of the pitch is increased. With pitches used in paving work the blowing of the tar is commenced much earlier than the finishing point, in order to agitate the contents of the still and prevent the deposition of carbon on the bottom. If this carbon is allowed to deposit, local heating of the plates takes place and the still is quickly ruined.

"After the tests in the laboratory have shown the refined tar to be of the correct consistency, the material is either run off by

gravity to cooling tanks, or in case the stills are on a low level, it is forced over by compressed air or by steam pressure into the coolers. The coolers are simply iron tanks open on all sides, so as to allow the free circulation of air and a quick cooling of the pitch. The cooling, however, even under favorable circumstances, requires a long time, and in the case of large cooling tanks several days elapse before the tar is of a temperature safe to run into barrels.

Production of Coal Gas and Coke Oven Tars. "At the present time about 55,000,000 gallons of tar are produced in gas houses in the United States, and about 110,000,000 gallons in coke oven plants. These supplies at present seem to be ample for all demands, and the amount of tar available is capable of large expansion in the near future through the conversion of plants making coke in beehive ovens into plants equipped with by-product coke ovens. Within the past year the by-product coke ovens installed have increased the tar supply by approximately 35,000,000 gallons. It has been estimated that there is a possible increase in this direction of perhaps 375,000,000 gallons."

Coke Oven Tar. This type of tar has been previously mentioned together with a tabular comparative analysis of coal gas tar and of coke oven tar. Considerable research work on this tar has been conducted by Prévost Hubbard, Assoc. Am. Soc. C. E., who describes * as follows the method of manufacture.

Manufacture. "While, in the manufacture of coal gas, the production of tar is absolutely unavoidable, this is not true of the manufacture of coke for metallurgical purposes. There are two general types of coke ovens in use at present, in one of which no attempt is made to recover the volatile products of the coal. This is the oldest form of oven, known as the 'beehive,' and is extensively used in this country to-day. It is constructed of brick and as its name implies has the form of a beehive. Bituminous coal is placed in this oven or kiln and

* See Circular 97, U. S. Office of Public Roads, "Coke-Oven Tars of the United States."

a part of it burned in order to carbonize the remainder, while the volatile products, such as gas, ammonia, and tar, are allowed to escape through an opening in the top of the kiln where they are lost in flame and smoke. Coke ovens in which the by-products are saved are now used to some extent in this country, and sooner or later will undoubtedly replace the old-style oven entirely, and thus increase our output of tar enormously.

Characteristics. "It will be noted that the gravities of the samples examined range from 1.133 to 1.214 and that the great majority are lower than 1.200. This in itself indicates low percentages of free carbon. The minimum percentage of free carbon was 2.73, the maximum 16.80, and the average for the 26 samples 8.38. Eighteen samples contained less than 10 percent of free carbon and 8 more than 10 percent. About two-thirds of these products might, therefore, be considered as low-carbon tars and the other third as medium-carbon tars. It is of interest to note than 14 of the pitch residues remaining after distillation had been carried to 315 degrees Centigrade were either soft or plastic—a condition which has seldom been noticed by the author in the distillation of gas-house coal tars. In an ordinary road tar for use in construction work where free carbon is present to the extent of about 20 percent the proportion of total distillate, below 315 degrees Centigrade, to pitch residue is approximately 1 to 4. Where this relation exists the pitch residue is hard and brittle. A residue which is soft or plastic is to be preferred, as it would indicate longer life during service, and where such a residue is present the proportion of distillate would naturally be lower for a given consistency, as the distillates may be considered as fluxes for the residues. If such is the case, it is evident that coke oven tars offer a valuable source of supply for tar road binders. As an example, even the highest-carbon tar, if distilled to the point where the proportion of distillate, below 315 degrees Centigrade, to the pitch residue was as 1 to 4, would contain less than 19 percent of free carbon, which is at present considered as not excessive for a refined coal tar."

Water Gas Tar. The methods of manufacturing refined

water gas tars and combinations of water gas tars and asphalts are well covered in the following description by W. H. Fulweiler,* Assoc. M. Am. Soc. C. E.

Process of Manufacturing Crude Water Gas Tar. "The manufacture of water gas depends upon the reaction between water vapor and incandescent carbon. The result of this reaction is what is known as water or blue gas composed of about equal parts of hydrogen and carbon monoxide. This gas has a heating value of about 300 B. T. U. per cubic foot, but it is non-luminous, so that for use in the open flame burners it has to be enriched by the addition of some hydrocarbon. Water gas as we now know it is manufactured in an internally fired generator and the enriching hydrocarbon is added in the form of oil in vessels called respectively the carburetor and the superheater.

"In the formation of water gas tars the oil or hydrocarbon vapor is fixed at a rather high and uniform temperature with a reasonably uniform time of contact, together with the fact that the reaction takes place in the presence of the blue gas, which is rich in hydrogen. This results in a relatively small amount of tar being formed, and provides the most efficient conditions for the complete transformation of all of the hydrocarbons into the more complex benzol series, the result being due to the regulation of the temperature and time of contact.

"When the tar which leaves the generating apparatus in the form of a vapor comes in contact with the water in the wash box of the machine, the greater portion is condensed. Some of it, however, remains in the form of mist, which is removed from the gas in the condensers and tar extractors, along with a considerable portion of the excess steam in the water gas. Owing to the low gravity of the crude tar, it does not immediately separate from the water and is, therefore, passed through tanks provided with baffling plates where it is partially separated from the water. It is then stored in large tanks, where under

* See 1912–1913 Lecture on "The Manufacture of Refined Water Gas Tar," before the Graduate Students in Highway Engineering at Columbia University.

the influence of gravity the tar gradually rises to the surface, practically free from water. Many mechanical devices have been used to insure this separation, but nothing seems quite as effective as long standing in large tanks.

Manufacture of Refined Water Gas Tar. "The water gas tar is charged into a fire still, and the distillation commenced. The first fraction cut is known as light oil, and has a gravity of 0.953, then comes the naphthalene oil of about 0.990. The next fraction cut is dead oil, which has a gravity of about 1.01, and following this comes creosoting oil, with a gravity of about 1.05. The distillation is finished at the end of the creosoting oil cut. The residue remaining in the still is either a road tar or a pitch, depending upon the temperature at which the distillation ceases. Varying grades of road tar or pitch result according to the temperatures at which distillation ceases. The higher the distillation temperature, of course, the harder the grade of pitch will be made.

Manufacture of Combinations of Water Gas Tars and Asphalts. "The road compound as it comes from the stills is run off into closed coolers, where its temperature is reduced, and is then combined with the required amount of asphalt or heavy oil, according to the grade of material that is being made. In all this work the material is handled by what are known as blow cases in which compressed air is the actuating medium instead of pumps. The mixing is done by an especially arranged series of nozzles operated with compressed air.

Methods of Shipping. "When the material has passed the laboratory test, if it is to be shipped in tank cars, it is blown from storage tanks into an overhead tank, where it is kept warm, if necessary, with steam coils. The cars may be run directly beneath this tank, which is provided with large valves, so that an 8,000 gallon tank car may be loaded in about ten minutes. In case the material is to be shipped in barrels or steel drums, it is run into another smaller blow case connected with a manifold series of pipes and is blown directly into the barrels. It is necessary, however, to cool the material to a lower temperature when barreling than when it is to be loaded in tank cars. This, of

course, requires more time. It is further necessary to weigh the barrels both light and loaded in order to determine the exact quantity of material in each barrel, which, according to many State regulations, is required to be marked on each barrel.

Production. "According to the census of 1909, there were 1,296 plants manufacturing illuminating and heating gases, excluding the coke ovens. These plants turn out a total of 150,835,793,000 cubic feet of gas, and of this number 572 plants manufacture carbureted water gas, producing approximately 105 billion feet of gas. From this gas there was made about 50,000,000 gallons of water gas tar, so that this represents approximately the total supply available."

Tests for Physical and Chemical Properties

Various tests have been devised in order to determine the physical and chemical properties of bituminous materials. Tests are made for control during the manufacture of bituminous materials, to obtain a record of the properties of materials used, and are employed in specifications to secure the materials desired for use in the construction and maintenance of roads and pavements. In this chapter typical tests which have been used will be described and brief interpretations of the results of such tests given. Specifications covering the chemical and physical properties of bituminous materials will be considered in the several chapters devoted to the construction and maintenance of bituminous surfaces and bituminous pavements.

Attention should be called to the interrelationship which exists among certain properties and the danger incurred by assigning limitations to the several properties covered in a given specification without considering the effect of each stipulated limitation upon the other properties included. Many are the instances where specifications have been drawn which are impracticable of fulfilment, since the combinations of properties have not existed in any commercial bituminous material. In speaking of the problems of this character which confront the chemist and engineer, the case has been well expressed by Charles

S. Reeve,* M. Am. Soc. for Testing Materials, who states that the engineer "cannot be governed entirely by theoretical considerations, but must be advised of the ability of the manufacturers to meet his requirements, and a lack of knowledge on this point has led to no end of righteous complaint on the part of the producers. Frequently the maximum and minimum limits of a particular clause are drawn unnecessarily close, and to control a product within such limits on a factory scale would prove next to impossible or an unjustifiable expense. Sometimes a clause is inserted which embodies the values of a newly devised test without any consideration or knowledge of the relation of these values to the other clauses of the specification, and thus a material is required which is wholly impossible to produce. The so-called 'impossible' specification is frequently the result of best intentions on the part of the engineer, who, in his effort to broaden and yet strengthen his specification, selects clauses here and there from several others which he knows to have given satisfaction. The writer has seen several wonderful examples of this practice in which the author of the specification had practically nullified the purpose which he had set out to accomplish. It is therefore particularly advisable that the highway engineer who is responsible for the purchase of bituminous materials to be used in his work should file a record of the tests on all such materials used, thus preserving valuable data for his guidance in the future when preparing specifications. Moreover, he is placed in a position to intelligently assert what he has been receiving as a ground for later demanding similar material."

The methods of testing bituminous materials presented include those proposed in 1909 by the Special Committee on "Use of Bituminous Materials in Road Construction" of the American Society of Civil Engineers, which are preceded by the abbreviations Com. Am. Soc. C. E. Method; those provisionally adopted by the American Society for Testing Materials, which are preceded by the abbreviations Am. Soc. Test. Mats.; and those

* See "The Value of Specifications and Tests for Bituminous Materials," presented at the 1912 American Association for the Advancement of Science Convention, at Cleveland, Ohio.

adopted or described by various departments, engineers, and chemists. Unless otherwise stated the quoted interpretations of the results of tests are by Prévost Hubbard, Assoc. Am. Soc. C. E., being abstracts from a "Communication" on the subject, "Various Materials in Use for the Purposes of Construction and Maintenance; Conditions to be Fulfilled; Tests; Units to be Adopted," which was presented for the United States to the Second International Road Congress held at Brussels in 1910.

WATER-SOLUBLE MATERIALS.

Com. Am. Soc. C. E. Method. Boil gently 2 grams with 25 cubic centimeters of distilled water for an hour. Filter and wash with 25 cubic centimeters of boiling water. Evaporate filtrate in weighed dish to dryness and constant weight at 105 degrees Centigrade. Weigh residue. Ignite residue and weigh again, giving weight of inorganic matter plus weight of crucible. Weight number 2 minus weight number 3 gives weight of organic matter.

SPECIFIC GRAVITY.

Com. Am. Soc. C. E. Method. Use some standard form of pycnometer. Material and distilled water must have a temperature of 25 degrees Centigrade. For semisolid and solid materials use Sommer's pycnometer.

*Sommer Pycnometer.** "The main feature of the method is to let the asphalt chill in a small cylindrical vessel which is divided into two parts, the lower holding exactly 10 cubic centimeters, and the upper being removable from the cup by the connecting thread. The principle of the instrument is to have the shrinkage take place in the upper, removable sleeve, so that after the removal of the same the lower cup contains a certain, fixed volume.

"The entire vessel is filled with melted asphalt and heated for a little while at a temperature slightly above the melting point, in order to thoroughly remove air bubbles or traces of water. After the surface is clear, the vessel is allowed to cool, at first in air (to avoid sudden contraction, and hence separation of the asphalt from the sides of the tube), and then in water of the desired temperature, which will usually be — degrees Fahrenheit. The sample should be left in the water a sufficient time to

* See Proceedings, American Society for Testing Materials, vol. ix, 1909.

thoroughly adopt its temperature, and a half-hour will not be too long for this purpose. Then it is removed from the water, wiped dry, and the upper extension part or 'sleeve' is removed. If the asphalt is so hard that it renders the unscrewing difficult, the upper part should be warmed with a Bunsen burner. The sleeve is then pulled off and the asphalt which extends above the level of the cup is cut off with a broad knife.

"The cup will then contain exactly 10 cubic centimeters of asphalt at — degrees Fahrenheit. This quantity can be directly weighed on an analytical balance, and the specific gravity ascertained by dividing the number of grams of asphalt by ten. The following method, however, simplifies the procedure:

"After the cup is filled flush, a cover is slid on it from the side, and fastened to it by a flange. The cup and its contents are then suspended from a special hydrometer and the whole instrument is placed in a jar containing water at — degrees Fahrenheit, and if any air bubbles form on the instrument it should be twisted once or twice quickly and they will escape. The specific gravity can then be read directly on the stem of the hydrometer without correction. The method is accurate to the third decimal place, and the slight mistake which could be caused by irregularity in the cutting is so trifling that it would not affect the third decimal place when only 10 cubic centimeters are used."

Interpretation of Test by Hubbard. "It is of value mainly as a means of identification, but when considered in connection with other tests is often of service in determining the suitability of the material for road purposes. As applied to oil and oil products, the specific gravity is a rough indication of the amount of heavy hydrocarbons which give body to the material. Crude petroleums vary in specific gravity from 0.73 to 0.98 and slightly higher, paraffin oils as a rule having the lowest specific gravity and asphaltic oils the highest. The former have practically no value for road work, while the latter constitute the most desirable type. Oils containing a semi-asphaltic base hold an intermediate position and will usually run higher in specific gravity than the paraffin oils and lower than the truly asphaltic oils.

"Crude coal tars vary in specific gravity from 1.10 to 1.22

and sometimes higher, while crude water-gas tars lie between 1.00 and 1.10. In coal tars, the specific gravity is largely dependent upon the percentage of free carbon or soot which it contains, those of low specific gravity holding but little and those of high specific gravity holding a large amount of free carbon. Thus a crude tar having a specific gravity of less than 1.15 will usually show less than 12 percent free carbon, while those running as high as 1.22 will have 30 percent and over. In refined tars specific gravity naturally increases with consistency, both because the lighter hydrocarbons and water have been removed and because the relative proportion of free carbon has been increased in the residue. In such products for a given consistency a low specific gravity is to be preferred to a high one. This is not true, however, when considering refined products of different consistencies, as in such cases, while the percentage of free carbon might be the same, the most desirable product might show the highest specific gravity for the reasons mentioned above."

Solubility in Carbon Disulphide.

Com. Am. Soc. C. E. Method. The free carbon shall be determined by dissolving for fifteen hours 2 grams of the compound in 100 cubic centimeters of cold carbon disulphide, filtering the solution through a weighed Gooch crucible fitted with an asbestos pad, drying to constant weight, and weighing the insoluble residue; then igniting crucible until all carbon is burned off, weighing the residue (ash). The difference between the second and third weights is "Free Carbon." The difference between the first and third is ash, which should be noted.

Am. Soc. Test. Mats. Proposed Provisional Method for the Determination of Soluble Bitumen.*

* The Committee, in presenting the Provisional Method for the Determination of Soluble Bitumen, wish it understood that they do not recommend it as the best for general use, as it is longer and in many cases gives no better results than other more expeditious methods, but only as a method to be resorted to in case of dispute, as it seems to have the widest range of applicability of any of the methods considered. Moreover, they wish it to be understood that with some classes of materials the method will show a lower percentage of soluble bitumen than many of the shorter methods.

Drying the Sample and Preparing it for Analysis. "It was decided, owing to the great variety of conditions met with in bituminous compounds, that it is impossible to specify any one method of drying that would be satisfactory in every case. It is therefore supposed that the material for analysis has been previously dried either in the laboratory or in the process of refining or manufacture, and that water, if present, exists only as moisture in the hydroscopic form.

"The material to be analyzed, if hard and brittle, is ground and spread in a thin layer in a suitable dish (iron or nickel will answer every purpose) and kept at a temperature of 125 degrees Centigrade for one hour. In the case of paving mixtures and road materials, where it is not desirable to crush the rock or sand grains, a lump may be placed in the drying oven until it is thoroughly heated through, when it can be crushed down into a thin layer and dried as above. If the material under examination contains any hydrocarbons at all volatile at this temperature, it will of course be necessary to resort to other means of drying. Tar or oils may be dehydrated by distillation and the water-free distillate returned to the residue and thoroughly incorporated with it.

Analysis of Sample. "After drying, from 2 to 15 grams (as may be necessary to insure the presence of 1 to 2 grams of pure bitumen) are weighed into a 150-cubic centimeter tared Erlenmeyer flask, and treated with 100 cubic centimeters of carbon disulphide. The flask is then loosely corked and shaken from time to time until all large particles of the material have been broken up. It is then set aside for 48 hours to settle. The solution is decanted into a similar flask that has been previously weighed. As much of the solvent is poured off as possible without disturbing the residue. The contents of the first flask are again treated with fresh carbon disulphide, shaken as before, and then put away with the second flask for forty-eight hours to settle.

"The liquid in the second flask is then carefully decanted upon a weighed Gooch crucible, 3.2 centimeters in diameter at the bottom, fitted with an asbestos filter, and the contents

of the first flask are similarly treated. The asbestos filter is made of ignited long-fiber amphibole, packed in the bottom of a Gooch crucible to the depth of not over ⅛ inch. In filtering no vacuum is to be used and the temperature is to be kept between 20 and 25 degrees Centigrade. After passing the liquid contents of both flasks through the filter, the residue on the filter is thoroughly washed and the residues remaining in them are shaken with more fresh carbon disulphide and allowed to settle for twenty-four hours, or until it is seen that a good subsidation has taken place. The solvent in both flasks is then again decanted through the filter and the residues remaining in them are washed until the washings are practically colorless. All washings are to be passed through the Gooch crucible.

"The crucible and both flasks are then dried at 125 degrees Centigrade and weighed. The filtrate containing the bitumen is evaporated, the bituminous residue burned, and the weight of the ash thus obtained added to that of the residue in the two flasks and the crucible. The sum of these weights deducted from the weight of substance taken gives the weight of soluble bitumen."

Interpretation of Test by Hubbard. "For practical purposes, all organic matter soluble in cold carbon bisulphide is considered as bitumen. Fluid oils are almost completely soluble in this material and also blown oils and oil pitches, unless they have been cracked to the point of producing free carbon. The solubility of the bitumen itself is entirely independent of its character and consistency, so that the amount and character of insoluble material are of most interest in this test. This material is of no value from the standpoint of road work, but indicates whether an asphalt has been employed in the preparation of the binder, also whether a product has been destructively distilled during its preparation, the determining factor in the former case being the amount of mineral matter present and the amount of organic material in the absence of mineral matter in the latter case. It is, of course, possible to adulterate a preparation so as to give misleading results, unless the analyst is

familiar with the characteristics which the addition of various solid native bitumen will produce in oils of different types.

"Tars with the exception of those produced in blast furnaces contain only a small fraction of one percent mineral matter. Practically all material insoluble in carbon bisulphide is, therefore, organic material, commonly known as free carbon. Any tar or tar product containing less than 4 percent free carbon may, almost without exception, be considered as originating in the manufacture of carbureted water gas and is the product of the destructive distillation of oil. Water gas tars or oil tars as they are often called will usually contain less than this amount even when refined to a specific gravity of 1.17, and crude water gas tar seldom exceeds 2 percent free carbon. Most crude coke oven tars will carry from 4 to 10 percent free carbon, unless they have been produced at very high temperatures, while the modern gas-house coal tars rarely show less than 15 percent and sometimes run as high as 30 percent and over."

VISCOSITY OR CONSISTENCY.

Com. Am. Soc. C. E. Method. "Temperatures at which viscosities will be determined are 100 degrees Centigrade and 25 degrees Centigrade. Penetrometer to be used in accordance with standard method on materials solid at above temperatures. Of materials on which at the above temperature the penetrometer cannot be used, the viscosity shall be determined by one of the following instruments: Engler Viscosimeter, Lunge Tar Tester, New York Testing Laboratory Viscosimeter."

Penetration. "The penetration shall be measured by a standard machine using 100 gram load and No. 2 needle. Use a flat-bottomed glass dish ⅞ inch in diameter and 1½ inches in height. Fill flush with top with material and allow same to stand at room temperature for half an hour. Immerse in water bath, covering material for one hour. Immerse needle to be used for five minutes in same bath. Test at once, making three determinations. The recorded penetration will be the average value. Temperature 4 degrees Centigrade and 25 degrees Centigrade. Residue must be melted at lowest possible temperature and thoroughly mixed by stirring."

Engler Viscosimeter and New York Testing Laboratory Viscosimeter. Clifford Richardson, M. Am. Soc. C. E., and C. M. Forrest, Assoc. M. Am. Soc. C. E., have described the methods of using the above apparatus and the limitations of each. "The viscosity of bituminous road materials is determined in the Engler viscosimeter at any temperature desired. The full quantity, 250 cubic centimeters, is placed in the apparatus and raised to the temperature at which it is desired to make the test. One hundred cubic centimeters is then permitted to flow into a graduated flask of the above capacity, and the time of flow in seconds noted. The result may be expressed either in seconds or by ratio compared with the time of flow of a similar quantity of water at 77 degrees Fahrenheit.

"Road binders should be too viscous for testing in the Engler apparatus at temperatures below 250 to 350 degrees Fahrenheit, and to determine the consistency of such materials at normal or slightly elevated temperatures, the New York Testing Laboratory float apparatus is employed.

"'The apparatus, which is made by Howard & Morse, Brooklyn, N. Y., consists of two parts, an aluminum float or saucer, and a conical brass collar. The two parts are made separately for reasons of economy, so that one or two of the floats will be sufficient for an indefinite number of brass collars.

"'In using the apparatus, the brass collar is placed upon a brass plate, the surface of which has been amalgamated and filled with the bitumen under examination, after it has been softened sufficiently to flow freely by gentle heating. The collar must be level-full, and as soon as the bitumen has cooled sufficiently to handle it is placed in ice water at 41 degrees Fahrenheit for fifteen minutes. It is then attached to a float and immediately placed upon the surface of the water, which is maintained at 90 degrees Fahrenheit or any other temperature desired.

"'As the plug of bitumen in the brass collar becomes warm and fluid, it is gradually forced out of the collar, and as soon as the water gains entrance to the saucer the entire apparatus sinks below the surface of the same.

"'The time, in seconds, elapsing between placing the appara

tus on the water and when it sinks is determined most conveniently by means of a stop watch, and is considered as the consistency of the bitumen under examination.'"

Am. Soc. Test. Mats. Method. "The penetration of bitumen shall be the distance expressed in hundredths of a centimeter that a No. 2 needle will penetrate into it vertically without friction at 25 degrees Centigrade under a stated weight applied for a stated length of time, the factors of weight and time being determined as follows:

"The material shall first be tested for five seconds under a weight of 100 grams. If this result is less than 10, the penetration shall be determined under a weight of 200 grams applied for one minute; if between 10 and 300, the penetration shall be determined under a weight of 100 grams applied for five seconds; if greater than 300, the penetration shall be determined under a weight of 50 grams applied for five seconds. In every case the factor of weight and time shall be stated when reporting the penetration, and whenever possible to obtain both readings, the penetration under a 100-gram weight for five seconds and under the modified weight and time shall both be reported. When testing material softer than 100 penetration, a containing receptacle not less than 1¼ inches in diameter shall be used.

"It is recommended that the penetration may be determined at 0 degrees Centigrade (32 degrees Fahrenheit) and 46 degrees Centigrade (114.8 degrees Fahrenheit), in addition to the 25 degrees Centigrade (77 degrees Fahrenheit) test."

Crosby Method.* "The apparatus (Crosby Consistometer) consists of an accurately balanced wheel, grooved at the circumference and provided with some measuring device to determine with accuracy the arc through which the wheel is turned. We have used two wheels in our experiments, one 8 inches in diameter, weighing 148.6 grams, the other 4 inches in diameter, weighing 31.1 grams. A thread passes around the circumference of the wheel, to which it is attached at one point

* See "A New Consistometer for Use in Testing Bituminous Road Materials," by W. W. Crosby, M. Am. Soc. C. E., 1911 Proceedings, Am. Soc. for Testing Materials.

to prevent slipping. At one end of the thread a small hook is used to attach the plungers, and at the other end is suspended a pan for weights. Sperm oil is used to lubricate the friction parts, which consist of pivots in the one case and a steel axle in the other. An excess load of 0.3 gram is required on one side or the other in both machines to overcome friction resistance, inertia, etc.

"The principle of the machine is to measure the distance traveled by a disk of known area and under a known load through a substance contained in a box of fixed dimensions, during a fixed interval of time, five seconds. The distance traveled is measured in tenths of a millimeter, and is the number sought. The plungers are all round disks of brass with spindles inserted in the center. All of these spindles are stiff and strong, 3–32 inch diameter wire, and about 2 inches long, except in the plunger marked 'No. 12 Special,' in which case it is more slender and is 5 inches long. The box in which the fluid is placed is the ordinary box used in the evaporation tests of tar and is 2½ inches in diameter, 1 inch high; in the case of very fluid substances, a box of the same diameter but 5 inches deep is used.

"In the testing of a substance, the plungers are immersed directly beneath the surface of the liquid, a correction being applied for the sustaining force of the liquid (which is evidently readily obtained from the specific gravity of the tar or oil and the determined relationship between the specific gravity of the plunger and its weight); and the weights are so adjusted on the balanced pan that a known weight is applied to the plunger. The brake is then released for five seconds, the plunger descends into the material, and the depth of its descent is read on the measuring device first mentioned."

Fixed Carbon.

Com. Am. Soc. C. E. Method. "About 1 gram of the compound is weighed into a platinum crucible 1⅛ to 1½ inches high. The crucible with the lid on is heated, first gently, and then until no more smoke and flame issue between the crucible and the lid. It is then heated 3½ minutes in the full heat of the burner; then cooled and weighed. The crucible lid is removed

and the crucible and contents allowed to remain in the full heat of the burner until the carbon is burned off, and then weighed again. The difference between these two weights is the 'Fixed Carbon.'"

Lester Kirschbraun, Consulting and Testing Engineer on Pavements, gives the following description * of the method recommended by the Committee on Coal Analysis of the American Chemical Society, published in Vol. 21 (1899), page 1116. "A sample of 1 gram of bitumen to be examined is weighed into a previously tared platinum crucible of about 30 cubic centimeters capacity, provided with a close-fitting cover. This is ignited for exactly seven minutes on a platinum triangle over a Bunsen burner carefully regulated so as to give a flame 6 to 8 centimeters high to the top of inner cone and fully 20 centimeters high to the tip. The platinum crucible is placed ½ centimeter above the tip of the inner cone. The ignition should be carried out on a place free from drafts and permitting a steady flame. At the end of seven minutes the crucible is removed from the flame, cooled in a desiccator, and weighed. It is then returned to the flame, uncovered, turned on its side to give access to air, and ignited until all carbonaceous matter is removed. The cover is ignited to remove carbon deposited upon the under side. The crucible and cover are again cooled and weighed, the weight subtracted from that previously obtained representing the fixed carbon. When the bitumen carries mineral matter containing carbonates, the ash in the crucible is treated with a few cubic centimeters of a saturated solution of ammonium carbonate, dried, and ignited at a low heat to remove excess of carbonate and the corrected weight of ash obtained.

"The percentage of fixed carbon is calculated to the weight of the original sample less the mineral matter obtained in the ashing. When notable amounts of 'free carbon' are present in

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* See paper entitled "Fixed Carbon, its Determination and Value in Specifications," presented at the 1912 Cleveland Meeting of the American Association for the Advancement of Science.

the bitumen, the result may be reported as fixed carbon less free carbon. The author, however, prefers to report the fixed carbon as obtained for the reason that the organic non-bituminous residues reported by the usual methods of extraction are probably seldom actual elemental carbon, but more often highly dehydrogenized hydrocarbon or hydrocarbon derivatives. In cases where it is desired to obtain a fixed carbon figure apart from such non-bituminous matter, a portion of the soluble bitumen may be recovered from extraction for this purpose."

Interpretation of Test by Hubbard. "The fixed carbon determination shows much the same thing as that for naphtha insoluble bitumen, as it serves as an indication of the mechanical stability of an oil. Paraffin oils show but little fixed carbon, while the asphaltic oils run higher and the asphalts still higher. The terms fixed carbon and free carbon should not be confused, as they have entirely different meanings. Free carbon always exists as such in the material, while fixed carbon is the coke resulting from the ignition of the bitumen in the absence of oxygen. Fixed carbon determinations are seldom made upon tars, as the presence of free carbon interferes with this test. Owing to a misconception as to what fixed carbon represents, specifications have sometimes been made limiting the percentage of this substance to a very low figure. Providing that free carbon is absent, comparatively high percentages of fixed carbon are a rather desirable property in oils, for the reason mentioned, especially if they are to be used in construction work."

EVAPORATION.

Com. Am. Soc. C. E. Method. "Heat 20 grams of compound in a flat-bottomed dish, 2½ inches in diameter and about 1 inch high, for a total of five hours in three successive periods of three, one, and one hour, respectively, in an oven, the interior of which is maintained at a uniform and constant temperature of 170 degrees Centigrade. This oven is to be controlled by any thermo-regulator, controlling within 2 degrees, and is to have its full temperature before the compound is introduced.

The dish must be level. Remove dish from oven and stir contents thoroughly for one minute between successive periods."

Am. Soc. Test. Mats. Provisional Method for the Determination of the Loss on Heating of Oil and Asphaltic Compounds. "The loss on heating of oil and asphaltic compounds shall be determined in the following manner: 20 grams of the water-free material shall be placed in a circular tin box with vertical sides, measuring about 2 centimeters in depth by 6 centimeters in diameter, internal measurement. The penetration of the material to be examined shall, if possible, be determined at 25 degrees Centigrade and the exact weight of the sample ascertained. The sample in the tin box shall then be placed in a hot-air oven (New York Testing Laboratory oven without fan), heated to 163 degrees Centigrade (325 degrees Fahrenheit), and kept at this temperature for five hours. At no time shall the temperature of this oven vary more than 2 degrees Centigrade from 163 degrees Centigrade. When the sample is cooled to normal temperature, it shall be weighed and the percentage of loss by volatilization reported. The penetration of the residue shall then, if possible, be determined at 25 degrees Centigrade as upon the original material, and the loss in penetration found by subtracting this penetration from the penetration before heating. In preparing the residue for the penetration test it shall first be heated and thoroughly stirred while cooling."

Interpretation of Test by Hubbard. "This test is a purely arbitrary one, but when applied to road oils will often prove of considerable value. It is believed that the loss in weight thus produced is a fair comparative indication of loss by volatilization suffered by the material in the course of time when applied to the road, also that the character of the residue is similar to that eventually left in the road. A determination of the consistency of this residue should if possible be made, and particular attention paid as to whether it is of a greasy or sticky nature. The volatilization test is not a quantitative determination of any one class of volatile oils present in the original

material, but only of its tendency to give up these volatile oils. If the material has a certain consistency which it is desired to maintain after application, it should show a low volatilization and should not be subject to hardening by oxidation or other causes. A determination of penetration of the residue as compared with that of the original material is of value in determining this fact. A material which must be soft and sometimes fluid on account of the desired method of application and character of the road treated, should very properly suffer high loss by volatilization in order that it may be capable of attaining proper consistency under service conditions.

"Fluid products to be used in the surface treatment of roads need not necessarily show a high loss by volatilization nor a great increase in the consistency of their residues, although the latter is a desirable property. They are mainly of value as dust preventives and binders for the thin coat of fine material upon the road surface and cannot affect the character of the road proper unless applied in large quantities. If their residues are not of a sticky nature, they will, however, produce an undesirable surface condition in wet weather unless applied in very small quantities. In general all residues should be sticky or adhesive, as otherwise they will act more as lubricants than as road binders. A paraffin oil will produce a greasy residue; an asphaltic oil will produce one that is sticky. While the latter may be successfully employed in road work, the former are worthless for this purpose.

"In certain instances, determinations of the so-called asphalt contents of oils have been made by driving off volatiles until the residue is of a certain consistency. To produce this residue it is often necessary to subject the bitumen to such high temperatures that chemical changes take place which would never occur under service conditions. For this reason the test is not a determination of the actual asphalt contents, but only of the ability of the oil to produce an asphaltic base of given consistency under the action of high temperatures. Such a test is, therefore, misleading and has resulted in much confusion among road engineers as to the relative binding value of oils."

Melting Point.

Com. Am. Soc. C. E. Method. "The material whose melting point is to be determined is melted and poured into a mould that will make a ½-inch cube. A 10-gauge wire about 6 to 8 inches long is bent at right angles for a length of ¾ inch at one end and the center of the cube is placed on this end so that one of the diagonals of the vertical face of the cube is parallel to the long part of the wire. Take a bottle of a size about 2 inches in diameter and 4 inches high and place a piece of white paper in the bottom of it. Pass the long part of the wire through the cork of the bottle so that the lower edge of the cube will be within 1 inch of the bottom of the bottle. Also put a thermometer through the cork so that the bulb is opposite the cube. Place the bottle in a water or oil bath and raise the temperature of the bath at a rate of 3 to 6 degrees Centigrade per minute. The melting point of the material is the temperature of the thermometer inside the bottle at the time that the material touches the paper in the bottom of the bottle."

Interpretation of Test by Hubbard. "A determination of the melting point of solid bitumens is mainly of value as a means of identification and for control work on the part of manufacturers. The melting point of a bitumen is directly related to its hardness and brittleness, but the relations are not the same for all classes. Thus, at normal temperature, a blown oil with a melting point of 50 degrees Centigrade is neither hard nor brittle, while a tar pitch is both. As the melting point rises, however, they both become harder and more brittle. The climate under which a bitumen is to serve as a road binder should be considered in connection with its melting point and this is particularly true of tar products.

"The desired method of application will also have to be taken into account. If the penetration or grouting method is to be followed, the melting point of a tar product should not exceed 25 degrees Centigrade and in a blown oil probably not be over 30 degrees or 35 degrees Centigrade, for the reason that if higher than this the material is apt to solidify too quickly upon coming into contact with the cold stone on the road, and will therefore

not penetrate to any extent. When the mixing method is to be employed using hot stone, the melting point of the bitumen may be as high as climatic conditions will allow."

DISTILLATION.

Com. Am. Soc. C. E. Method. "The distillation is determined up to 105 degrees Centigrade, from 105 to 170 degrees Centigrade, from 170 to 225 degrees Centigrade, from 225 to 270 degrees Centigrade, from 270 to 300 degrees Centigrade. Seven hundred grams of the compound are weighed into a retort (Eimer and Amend 4-pint No. 4521), whose top is fitted with a tee, as close as possible to the retort, and a condenser pipe 24 to 36 inches long; the upper branch of the tee is used for the insertion of a thermometer, the top of whose bulb is placed immediately below the main outlet of the tee."

Proposed Tentative Method of Distillation.*

"Apparatus—The apparatus shall consist of the following standard parts:

"Flask—The distillation flask shall be a 250-cubic centimeter Engler distilling flask, having the following dimensions:

Diameter of bulb	8.0	cm.
Length of neck	15.0	"
Diameter of neck	1.7	"
Surface of material to lower side of tubulature	11.0	"
Length of tubulature	15.0	"
Diameter of tubulature	0.9	"
Angle " "	75	degrees

"A variation of 3 percent from the above measurements will be allowed.

"Thermometer—The thermometer shall be of hardened glass, filled with carbon dioxide under pressure and provided with an expansion chamber at the top; it shall read to 450 degrees Centigrade, and shall be graduated in single degrees Centigrade, and shall have the following dimensions:

* See Proceedings of the American Society for Testing Materials, vol. xi, 1911, p. 241.

Diameter of stem	6.75	to	7.25	mm.
Length of thermometer	335	"	350	"
" from 0° to 450° marks	285	"	300	"
" of bulb	20	"	22	"
Diameter of bulb	5.25	"	6.50	"

"It shall rise from 15 degrees to 95 degrees in not less than three seconds or more than five seconds when plunged into boiling water.

"The thermometer shall be set up as for the distillation test, using water, naphthalene, and dimethylamine as distilling liquids. The correctness of the thermometer shall be checked at 0 degree Centigrade and 100 degrees Centigrade after each third distillation until seasoned.

"Condenser. The condenser tube shall have the following dimensions:

Length of tube			500	mm.
Width of "	12	to	15	"
Width of adaptor end of tube	20	"	25	"

"Stands. Two iron stands shall be provided, one with a universal clamp for holding the condenser and one with a light grip arm with a cork-lined clamp for holding the flask.

"Burner and Shield. A Bunsen burner shall be provided, with a tin shield 20 centimeters long by 9 centimeters in diameter. The shield shall have a small hole for observing the flame.

"Cylinders. The cylinders used in collecting the distillate shall have a capacity of 25 cubic centimeters, and shall be graduated in tenths of a cubic centimeter.

"Setting up the Apparatus. The thermometer should be placed so that the top of the bulb is opposite the middle of the tubulature. All connections should be tight.

"Method. One hundred cubic centimeters of the dehydrated material to be tested shall be placed in a tared flask and weighed. After adjusting the thermometer, shield, condenser, etc., the distillation is commenced, the rate being so regulated that 1 cubic centimeter passes over every minute. The receiver is changed as the mercury column just passes the fractionating point.

"The following fractions should be reported:

Start of distillation	to	100	degrees	Centigrade
110 degrees C.	"	170	"	"
170 "	"	235	"	"
235 "	"	270	"	"
270 "	"	300	"	"
Residue				

"To determine the amount of residue, the flask is weighed again when distillation is complete. During the distillation the condenser tube shall be warmed when necessary to prevent the deposition of any sublimate. The percentage of fractions should be reported both by weight and by volume."

Distillation with Electric Still. An electric still adapted for difficult distillations has been described in detail by Irving C. Allen and W. A. Jacobs.*

Interpretation of Test by Hubbard. "The distillation test as applied to tars is a very valuable one, both for the purpose of ascertaining their road-building properties and method of preparation if they are refined products. All crude tars contain water which of course appears in the first fraction to 110 degrees Centigrade. In coal tars this water is ammoniacal, while in water-gas tars it is not. No tar containing water should be employed as a permanent binder and even in temporary binders its presence is detrimental.

"When a mixture of tar and oil products is suspected, the distillation test will often decide the matter very definitely. Petroleum and tar distillates obtained between two given temperatures will vary in specific gravity, the petroleum distillate being lighter than the tar distillate. If distillation is conducted carefully, a separation of these two products will take place in the receiver, forming two distinct layers of oil. This will not happen if either a pure tar or pure petroleum product is distilled. If desired, the separate distillates may be identified by suitable chemical means. Any naphthalene which may pass over and

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* See Bulletin 19, Bureau of Mines, U. S. Department of the Interior, entitled "Physical and Chemical Properties of the Petroleums of the San Joaquin Valley of California."

precipitate out of the distillate is almost conclusive evidence of the presence of tar. Both the tar and petroleum distillates have very characteristic odors, which may usually be distinguished even in a mixture of the two."

MATERIAL SOLUBLE IN COLD CARBON TETRACHLORIDE.

Com. Am. Soc. C. E. Method. "Same method as for Free Carbon, except carbon tetrachloride is used as a solvent instead of carbon disulphide."

PARAFFIN.

Com. Am. Soc. C. E. Method. "One hundred grams or less of the compound is distilled rapidly in a retort to dry coke. Five grams of the well-mixed distillate are treated in a 2-ounce flask with 25 cubic centimeters Squibb's absolute ether; after mixing thoroughly, 25 cubic centimeters Squibb's absolute alcohol are added and the flask packed closely in a freezing mixture of finely crushed ice and salt for at least thirty minutes. Filter the precipitate quickly by means of a suction pump, using a No. 575 C. S. and S. 9-centimeter hardened filter paper. Rinse and wash flask and precipitate (with 1:1 Squibb's alcohol and ether, mixture cooled to 17 degrees Centigrade) until free from oil (50 cubic centimeters of washing solution is usually sufficient). When sucked dry, remove paper, transfer waxy precipitate to small glass dish, evaporate on steam bath, and weigh paraffin remaining on dish. Calculation: Weight of paraffin divided by weight of distillate taken and multipled by percent of total distillate used from original sample equals percent of paraffin."

Interpretation of Test by A. W. Dow, M. Am. Inst. Chem. E., and Francis P. Smith, M. Am. Soc. C. E.* "We are decidedly of the opinion that the scale paraffin test *per se* should not be regarded as a measure of the value of bituminous compounds for road-making or paving purposes:

"(1) Because there is no evidence to show that the finding of scale paraffin by the modified Holde method, in which the material under examination is first distilled in the laboratory, is proof that scale paraffin or any detrimental form of paraffin is present in the bituminous material.

* See *Engineering News*, June 8, 1911, pp. 680–683.

"(2) Because there is no evidence to prove that paraffin of any kind is a deleterious constituent for a bituminous road cement."

Solubility in 88 Degree Baumé Naphtha.

Com. Am. Soc. C. E. Method. "Two grams of compound are placed in a 4-ounce oil sample bottle made up to 100 cubic centimeters with 88 degree Baumé naphtha, having a boiling point between 40 degrees Centigrade and 55 degrees Centigrade, the whole well shaken until compound is broken up. The bottle is then centrifugalized for ten minutes, 50 cubic centimeters are withdrawn into a weighted flask, the naphtha distilled by a water bath, and the residue weighed. Another 10 cubic centimeters of the naphtha solution is run over 3½-inch Petri glass and allowed to evaporate for 24 hours at room temperature. Note character of residue, whether sticky or oily."

Interpretation of Test by Hubbard. "As applied to oils and oil products, this determination is of value as indicating the amount of body-forming hydrocarbons which give mechanical stability to the material. No oils carrying less than 4 percent naphtha-insoluble bitumen will prove of service other than as dust preventives. Crude paraffin oils are almost entirely dissolved by this solvent, while the asphaltic oils contain very appreciable amounts of naphtha-insoluble bitumen. Residual oils carry larger quantities than the crude oils from which they are produced, and blown oils in particular show very high percentages of insoluble hydrocarbons, sometimes running as high as 25 or 30 percent. In this type of oil the naphtha-insoluble bitumen increases with the amount of blowing to which the oil has been subjected.

"Asphaltic cements containing appreciable quantities of these solid products will necessarily show relatively high percentages of bitumen insoluble in naphtha. While the binding value of asphaltic oils and cements is undoubtedly dependent upon the presence of the naphtha-insoluble hydrocarbons, variations in the character of these hydrocarbons exert a marked influence upon the characteristics of the original material. Bitumens insoluble in naphtha are commonly known as asphaltenes, while

those soluble are called malthenes. It should be understood, however, that both terms cover a multitude of hydrocarbons which vary greatly among themselves. The character of the naphtha-soluble bitumen is of interest from the standpoint of road treatment, that which is sticky after the solvent has been evaporated indicating better road-building qualities in the original material than that which is greasy."

FLASH AND BURNING POINTS.

Open-Cup Method for Flash Point Used by the New York State Highway Department. "About 40 grams of the material to be tested are placed in a 3-ounce seamless tin box. The box containing the material is placed on a sand bath over a Bunsen burner. The bulb of a thermometer is placed in the material, but so adjusted as not to touch the bottom of the box. The flame of the Bunsen burner is so adjusted that the temperature of the material being tested is raised at the rate of from 10 degrees to 15 degrees Fahrenheit per minute. As soon as vapors are seen coming off, the small flame from a capillary tube is passed over the center of the liquid and about ¼ inch above it, and repeated for about every 5 degrees Fahrenheit rise in temperature until the slight explosion indicates the flash point is reached. The temperature at this point is recorded as the open flash point of the material being tested."

Closed-Cup Method for Flash and Burning Points Used by the U. S. Office of Public Roads.*

Flash Point. "The oil cup should first be removed and the bath filled with water or cottonseed oil. The oil may always be used and is necessary for bitumens flashing at a temperature of over 100 degrees Centigrade. The oil cup should be replaced and filled with the material to be tested to within 3 millimeters of the flange joining the cup and the vapor chamber above. The glass cover is then placed on the oil cup and the thermometer so adjusted that its bulb is just covered by the bituminous material. The Bunsen flame should be applied in such a manner

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* See Bulletin No. 38, "Method for the Examination of Bituminous Road Materials," by Prévost Hubbard and Charles S. Reeve.

that the temperature of the material in the cup is raised at the rate of about 5 degrees Centigrade per minute. From time to time the testing flame is inserted in the opening in the cover to about half-way between the surface of the material and the cover. The appearance of a faint bluish flame over the entire surface of the bitumen shows that the flash point has been reached and the temperature at this point is taken."

Burning Point. "The burning point of the material may now be obtained by removing the glass cover and replacing the thermometer in a wire frame. The temperature is raised at the same rate and the material tested as before. The temperature at which the material ignites and burns is taken as the burning point."

Interpretation of Flash-Point Test by Hubbard. "This determination is of little value other than as a quick means of differentiating between the heavy crude oils and cut-back products and the fluid residuums, although it also indicates the point to which a refined oil has been distilled. Crude oils have, of course, a lower flash point than residual oils, and among the crude oils themselves those of a paraffin nature usually flash at a lower temperature than the asphaltic. The former may run as low as ordinary temperature, while the latter are sometimes as high as 135 degrees Centigrade. Some crude asphaltic oils will, however, show quite as low flash point as the paraffin oils, so that no great dependence can be placed upon this difference in crude petroleums. The flash point of residual road oils commonly exceeds 200 degrees Centigrade, while that of cut-back products will vary greatly, according to the flash point of the flux and the percentage and character of the heavier residual product. Thus, in a certain instance, when 90 percent of a distillate having a flash point of 100 degrees Centigrade was mixed with 10 percent of an oil asphalt having a flash point of 260 degrees Centigrade, the flash point of the resulting mixture was raised to 143 degrees Centigrade, and the addition of 60 percent of the heavier product only increased this temperature by 5 degrees. Great care should, of course, be taken when heating low-flash-point oils in an open kettle or tank that the oil does not catch fire. Such oils, however,

rarely require heating before application, as they are usually quite fluid when cold."

Ductility.

Dow and Smith Method. A. W. Dow, M. Am. Inst. Chem. E., and Francis P. Smith, M. Am. Soc. C. E., have described the method used by them as follows: "The ductility of an asphalt, asphalt cement, or bitumen shall be determined by ascertaining the distance in centimeters that a standard briquette of the material will draw out before breaking under the conditions hereinafter specified. The test shall be made either upon the commercially pure homogeneous asphalt cement or on the pure bitumen cement obtained by extracting the asphalt with a solvent or the purified bitumen from the non-homogeneous asphalt cement obtained by straining it through sieves.

"The material to be tested is poured into the mould while in a molten state, a slight excess being added to allow for shrinkage on cooling. After the cement is nearly cooled, the briquette is smoothed off level by means of a heated palette knife or trowel wet with water to prevent its sticking. It should then be thoroughly cooled to the temperature at which it is desired to make the test, after which the clamp and the two side pieces should be removed, leaving the briquette of asphalt cement held at each end by the ends of the mould, which now play the part of clips. The briquette shall then be immersed in water maintained at 77 degrees Fahrenheit for at least thirty minutes before testing and the test shall be performed while the briquette is so immersed in the water at the above temperature, and at no time shall the temperature of the water vary more than one-half a degree from the standard temperature. The test is made by pulling the two clips apart at a uniform rate of speed by means of hooks inserted in the eyes. The clips shall be pulled apart at the rate of 5 centimeters a minute until the thread of asphalt cement has parted. The distance between the clips shall then be measured in centimeters, and this distance, less the 3 centimeters originally separating the clips, shall constitute the ductility of the material examined."

TOUGHNESS.

New York State Highway Department Method. "The toughness test is made on a ball of the material 2 inches in diameter. The test is usually made at 0 degree Centigrade and the ball of the material is allowed to stand submerged in water at that temperature, for the two hours previous to making the test. The test is made by placing the ball in an impact machine where it is subjected to the blows of a 2 kilogram hammer, transmitted through a 1 kilogram plunger, the plunger having a spherical head of 1 centimeter radius. The first blow is through a distance of 5 centimeters and each succeeding blow is from a height 5 centimeters greater than the preceding one. The number of centimeters through which the hammer drops when fracture occurs is the number which represents the toughness of the material."

SULPHUR.

Hempel and Graefe Method. Dr. Albert Sommer, Assoc. Am. Soc. C. E., describes the following method * for the determination of sulphur in bituminous material: "The principle of this method consists in the combustion of the bitumen in an atmosphere of oxygen. This was at first suggested by Hempel, and later modified by Graefe for coal products and was successfully applied in the author's laboratory on oils and asphalts. About 0.2 gram of bitumen is weighed and placed on a small lump of chemically pure cotton, which must be free from sulphur. This is then placed on a small platinum cone which, again, is suspended from a copper wire. The cotton containing the bitumen is connected to a thin platinum wire, forming a short-circuit between the suspending copper wire and another wire through which an electric current can be sent coming from a dry battery. The current will thus ignite the thread the cotton, and finally the asphalt, which will burn freely in the oxygen. After combustion is completed a solution of sodium peroxide is permitted to enter the flask. Care should be taken that this be done either

* See *Journal of Industrial and Engineering Chemistry*, vol. ii, No. 5. May, 1910.

after the bottle is cold, or that the surplus pressure is released gradually through the solution of sodium peroxide, in which case it would retain all sulphurous gases. Determination of sulphur is finally accomplished by neutralization and precipitation of the solution with barium chloride. With a sufficient number of apparatus it is easy to execute two dozen sulphur analyses per day. They are accurate almost to the theoretical point which has been established by a number of experiments."

TAR IN ASPHALT.

Sommer Method.* "The principle of the method consists in distilling the bitumen to coke, and applying dimethylsulfate to the same. Dimethylsulfate dissolves oil products of benzene character or pyro distillates, whereas it does not dissolve paraffin or olefine hydrocarbons, such as are produced by the distillation of mineral oil. E. Graefe has applied this reaction to separate brown coal or shale distillate from coal tar products, and the writer found that it represents an ideal means of separating all distillates obtained from pyro-bitumen, or all benzene derivatives from petroleum distillates, which, of course, consist largely of paraffin chains or other saturated hydrocarbons.

"The method as executed in the writer's laboratory is as follows: Four cubic centimeters of the distillate obtained by destructive distillation of the asphalt (to coke) are put in a 10 cubic centimeter graduated cylinder with ground glass stopper, and 6 cubic centimeters of dimethylsulfate are added and shaken thoroughly for one minute. If the distillate is not entirely soluble, separation takes place within a few minutes and a separating mark can be accurately read. The percentage of solubility is calculated from this reading."

EXTRACTION OF BITUMEN FROM BITUMINOUS AGGREGATES.

U. S. Office of Public Roads Method.† "The extractor was designed upon lines suggested by an examination of machines in

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* See *Journal of Industrial and Engineering Chemistry*, vol. ii, No. 5, May, 1910.

† See Bulletin No. 38, "Methods for the Examination of Bituminous Road Materials," by Prévost Hubbard and Charles S. Reeve.

use by A. E. Schutte and C. N. Forrest. It consists of a one-fifth horse-power 1,100 revolutions per minute vertical-shaft electric motor with the shaft projecting into a cylindrical copper box, the bottom of which is so inclined as to drain to a spout. Upon a 3⁄16-inch circular brass plate 9½ inches in diameter rests a sheet-iron bowl, which is 8½ inches in diameter by 2 5⁄16 inches high, and has a 2-inch circular hole in the top. Fastened to the inner side of the bowl is a brass cup, having a circle of ⅛-inch holes for the admission of the solvent, and terminating in the hollow axle, which fits snugly through a hole at the center of the brass plate. The bowl may be drawn firmly against a felt-paper ring ¾ of an inch wide, by means of a 2½-inch milled nut, for which the hollow axle is threaded for a distance of ¾ inch directly below the upper surface of the plate. The axle fits snugly over the shaft of the motor, to which it is locked by a slot and cross pin.

"The aggregate is prepared for analysis by heating it in an enamel-ware pan on the hot plate until it is sufficiently soft to be thoroughly disintegrated by means of a large spoon. If a section of pavement is under examination, a piece weighing somewhat over 1 kilogram may be cut off with hammer and chisel. The disintegrated aggregate is then allowed to cool, after which a sufficient amount is taken to yield on extraction from 50 to 60 grams of bitumen. It is placed in the iron bowl and a ring ¾ of an inch wide, cut from the felt paper, is fitted on the rim, after which the brass plate is placed in position and drawn down tightly by means of the milled nut. The bowl is now placed on the motor shaft and the slot and pin are carefully locked. An empty bottle is placed under the spout and 150 cubic centimeters of carbon disulphide are poured into the bowl through the small holes. The cover is put on the copper box and, after allowing the material to digest for a few minutes, the motor is started, slowly at first in order to permit the aggregate to distribute uniformly. The speed should then be increased sufficiently by means of the regulator to cause the dissolved bitumen to flow from the spout in a thin stream. When the first charge has drained, the motor is stopped and a fresh portion

of disulphide is added. This operation is repeated from four to six times with 150 cubic centimeters of disulphide. When the last addition of solvent has drained off, the bowl is removed and placed with the brass plate uppermost on a sheet of manila paper. The brass plate and felt ring are carefully laid aside on the paper and, when the aggregate is thoroughly dry, it can be brushed on a pan of the rough balance and weighed. The difference between this weight and the original weight taken shows the amount of bitumen extracted."

Typical Analyses of Bituminous Materials

In order to show the methods of recording the results of tests and the general interrelationship between the various chemical and physical properties, Table No. 17, compiled by Wm. H. Connell, Assoc. M. Am. Soc. C. E., has been inserted in this chapter. The tests were made in accordance with the methods proposed in 1909 by the Special Committee on Bituminous Materials for Road Construction of the American Society of Civil Engineers.

Sampling and Shipping of Bituminous Materials

The following methods of sampling and instructions relative to shipping of bituminous materials have been standardized by the New York State Highway Department.

" Sampling. Under present arrangements bituminous material is sampled in one of three ways, as follows:

" **Sampled at Destination.** Bituminous material is sampled at its destination by an employee of the Division Engineer's office who submits the sample for test. Upon completion of tests the Division Engineer is notified of the acceptance or rejection of the material and he transmits the information to the Engineer of the road.

" **Sampled at Factory; Accepted or Rejected in Transit.** Bituminous material is sampled at the factory by an inspector of the Bureau who submits the samples for test and permits the

TYPICAL ANALYSES OF BITUMINOUS MATERIALS

TABLE No. 17.

FROM TRANS. AM. SOC. C. E., VOL. LXXV, PAGES 632–633.

	Sec. 1. Bermudez Asphalt.	Sec. 2. Bermudez Asphalt.	Sec. 3. Bermudez Asphalt.	Sec. 4. Standard Oil Special Binder.	Sec. 5. Texaco No. 55 Special Asphalt.	Sec. 5. Texaco Macadam Binder.	Sec. 8. Tarvia X.	Sec. 9. U. S. Tar and Asphalt 10%.	Sec. 9. Bermudez Asphalt for 15% mixture.	Sec. 9. Water-Gas Tar and Bermudez Asphalt 15%.	Sec. 9. Water-Gas Tar and Bermudez Asphalt 15% (mixed on work).	Sec. 9. Bermudez Asphalt.	Sec. 10. Water-Gas Tar.	Sec. 11. Tarvia X.	Sec. 12. Sanford and Strain's Asphalt Binder.	Sec. 16. Bermudez Asphalt.	Sec. 17. Standard Oil Binder B.	Sec. 18. Standard Oil Binder A.
Specific gravity	1.063	1.061	1.049	1.020	1.005	0.979	1.254	1.159	1.044	1.185	1.172	1.072	1.193	1.251	0.999	1.035	1.076	0.988
Soluble in H_2O.:																		
Organic	0.09%	0.11%	0.13%	0.023%	0.02%	0.01%	0.27%	0.045%	0.13%	0.08%	C.12%	0.10%	0.07%	0.54%	0.04%	0.11%	0.12%	0.08%
Inorganic	0.04%	0.05%	0.06%	0.023%	0.00%	0.03%	0.06%	0.091%	0.09%	0.08%	0.04%	0.07%	0.07%	0.07%	0.04%	0.06%	0.00%	0.00%
Free carbon	3.94%	4.39%	0.05%	0.69%	0.57%	0.18%	23.56%	4.96%	2.94%	3.54%	2.58%	6.47%	6.85%	24.26%	0.41%	3.10%	1.13%	0.35%
Ash	2.07%	2.77%	2.35%	0.04%	0.16%	0.09%	0.41%	1.07%	0.14%	0.35%	0.32%	1.43%	0.08%	0.18%	0.11%	1.70%	0.16%	0.11%
Soluble in cold carbon tetrachloride	*	*	*	99.17%	99.10%	99.66%	......	56.62%	96.75%	70.28%	91.63%	92.95%	......	......	99.41%	96.58%	96.33%	99.41%
Fixed carbon	18.84%	17.89%	17.82%	20.50%	15.86%	10.36%	39.40%	28.18%	18.54%	28.73%	26.65%	22.25%	33.96%	39.55%	11.80%	17.34%	22.10%	18.08%
Paraffin	*	*	*	1.44%	0.28%	0.34%	......	0.03%	0.31%	0.70%	0.20%	0 .55%	......	......	0.14%	0.45%	1.66%	1.85%
Melting point of normal material	212° F.	215° F.	207° F.	194° F.	237° F.	139° F	145° F.	171° F.	194° F.	174° F.	165° F.	180° F.	199° F.	132° F.	191° F.	188° F.	177° F.	95° F.
Evaporation 5 hours at 170° C.	4.21%	3.62%	*	gain of 0.06%	gain of 0.2%	7.84%	5.14%	8.14%	5.35%	3.56%	5.76%	3.47%	4.46%	6.05%	4.37%	4.73%	0.79%	0.08%
Melting point of residue	221° F.	217° F.	*	200° F.	237° F.	169° F.	174° F.	217° F.	228° F.	191° F.	192° F.	206° F.	220° F.	158° F.	228° F.	218° F.	207° F.	122° F.
Penetration of residue at 4° C.	2.2	2.6	*	4	8	23	6	0	3	1	0	5	0	4	7	5	20	84
Penetration of residue at 25° C.	16.3	18.4	*	53	36	133	56	9	8	26	24	30	4	111	16	11	189	soft
Evaporation 5 hours at 205° C.	7.35%	4.73%	1.96%	0.20%	0.78%	12.63%	9.27%	11.56%	8.63%	12.88%	19.16%	8.51%	8.07%	6.88%	8.73%	5.48%	3.18%	0.73%
Melting point of residue	237° F.	223° F.	211° F.	216° F.	258° F.	202° F.	187° F.	237° F.	248° F.	214° F.	235° F.	226° F.	230° F.	178° F.	247° F.	220° F.	233° F.	129° F.
Penetration of residue at 4° C.	1.6	2.6	4.5	4	5	17	2	0	1	0	0	1	0	1	6	4	16	51
Penetration of residue at 25° C.	9.5	16.5	36.9	25	28	84	23	4	5.4	4	1.5	10	0	75	10	9	55	soft
Solubility in 88° B. naphtha	78.68%	69.17%†	78.65%	80.30%	59.21%	61.18%	......	59.21%	71.23%	31.06%	60.61%	57.86%	......	......	63.68%	79.24%	66.48%	88.27%
Character of solution (oily or sticky)	sticky	sticky	sticky	sticky	sticky	sticky	......	oily	sticky	oily	oily	sticky	......	......	oily	sticky	......	oily
Distillation:																		
Up to 105° C.	......	......	......	......	......	......	0.00%	0.00%	......	0.00%	0.00%	......	0.00%	0.00%	......	......	......	......
105° to 170° C.	......	......	......	......	......	......	0.00%	0.00%	......	0.00%	0.00%	......	0.00%	0.00%	......	......	......	......
170° to 225° C.	......	......	......	......	......	......	0.09%	0.00%	......	0.24%	1.27%	......	0.00%	0.00%	......	......	......	......
225° to 270° C.	......	......	......	......	......	......	1.21%	0.00%	......	0.14%	7.16%	......	0.67%	7.92%	......	......	......	......
270° to 300° C.	......	......	......	......	......	......	6.18%	1.13%	......	0.54%	0.56%	......	0.50%	4.23%	......	......	......	......
Viscosity 100° C.:																		
Penetrometer	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
N. Y. T. L. Visc.	1′ 15″	1′ 21″	1′ 24″	42″	1′ 43″	20″	19″	45″	55″	36″	22″	49″	62″	24″	45″	41″	2′ 32″	18″
Viscosity 25° C.:																		
Penetrometer	37.6	41	51.5	113.8	47.3	......	......	102.2	117.7	136.5	243	118	25.1	......	93.7	146	......	......
N. Y. T. L. Visc.	......	......	......	......	......	10′ 7″	32′ 50″	......	......	......	......	......	......	29′ 8″	......	......	soft	8′ 38″

* Sample insufficient for these determinations.

† Used 86° B. naphtha

immediate shipment of the material in an officially-sealed car. Upon completion of tests the Division Engineer is notified of the acceptance or rejection of the material in the car shipped and he transmits the information to the Engineer on the road. As the material in the car mentioned may be rejected while in transit the receipt of an officially sealed car is not an acceptance of material. No material should be used without receipt of notification of acceptance for same.

"**Sampled at Factory and Accepted at Factory.** Bituminous material is sampled at factory by an inspector of this Bureau who submits the samples for test, and does not permit shipment of the material until informed of its acceptance. He then permits shipment of the material in an officially-sealed car and sends notification of this shipment to this Bureau, which forwards this notification of shipment of accepted material to the Division Engineer for transmission to the Engineer on the road."

SHIPMENTS.

"**Barrel Shipments.** One sample is to be taken for every 20 or 25 barrels when bituminous material is shipped in barrels, and care is to be taken to sample barrels from different parts of the shipment so that the lot of samples secured may be representative of the whole shipment.

"**Tank Car Shipments.** One sample is to be taken for every 2,000 or 2,500 gallons when bituminous material is shipped in tank cars, care being taken to secure the samples from equally distributed levels in the car so that the lot of samples secured may be representative of the whole shipment.

"**Loose Bulk Shipments.** One sample is to be taken for every 5 or 6 tons when material of the mineral bitumen class is shipped in loose bulk, care being taken to secure the samples from different levels and locations in the shipment so that the lot of samples secured may be representative of the whole shipment. Samples are not to be taken from the surface of the material."

Cost Data

As a rule asphaltic products cost more than tar products. The fluid and semisolid materials are generally sold by the gallon, solid materials by the short ton. Material bought in tank cars is cheaper than the same material bought in barrels, since the cost of the barrel adds about 1.5 cents per gallon to the price if the barrels have to be destroyed. The cost of some of the different materials is approximately as follows: light asphaltic oils, 3.5 to 5.5 cents per gallon; heavy asphaltic oils, 7 to 12 cents per gallon; light refined tars, 5 to 7 cents per gallon; heavy refined tars, 6.5 to 9 cents per gallon; asphalts $15 to $30 per short ton. The following bids were submitted in Brooklyn in 1912 on 2,000 short tons of asphalt cement. In the first column of figures the price per short ton is given; in the second column percent of bitumen soluble in carbon disulphide; in the third column, price on the basis of 100 percent bitumen:

Barber Asphalt Paving Company			
Mexican	$15.25	99.5 percent	$15.33
Trinidad	20.80	56 "	37.14
Bermudez	27.25	95 "	28.68
Texas Company			
Texas	18.50	99.8 percent	18.54
U. S. Asphalt Refining Company			
Mexican	19.17	99.5 percent	19.27
Union Oil Company			
California	22.38	99.5 percent	22.49

CHAPTER XI

DUST PREVENTION BY THE USE OF PALLIATIVES

Formation of Dust. Before considering the effects of dust and the methods of alleviating the nuisance caused by its presence, a study of the sources from which street dust arises is of value. A self-evident source of dust is the mechanical abrasion by traffic of the road or street surface. It is manifest that the degree of abrasion will depend upon the amount and nature of the traffic, the kind of material used, and the method of construction and maintenance employed. Other sources of street dust depending upon traffic are the deposition of dirt which has adhered to the wheels of vehicles coming from adjacent earth, gravel, or macadam streets, from the leakage of the contents of loaded vehicles both in transit and while loading and unloading, and from the excrement of animals. All street dust is by no means the result of traffic. In sections where shade trees are common, a source of dust is to be found in the decay of twigs, bark, and leaves, while pollen, seeds, and spores of various plants are further sources. Mineral matter applied to certain street surfaces to prevent slipperiness is a constant source of dust. Dust resulting from manufacturing enterprises frequently forms a very considerable part of street dust. Mills where pulverizing is carried on, textile establishments, and foundries are prolific sources of dust, while soot and fine ashes from chimneys find their way to the streets. From the nature of these sources it is apparent that the composition of street dust is extremely varied and complex.

Effects of Dust. Aside from its pathogenic effects, other ways in which dust acts as an enemy to the public welfare are as follows: the formation of heavy dust clouds by the traffic to such an extent as to obscure a view of the traveled way; when wet, the formation of mud which may cause skidding of

wheels and dangerous footing for both man and beast; its action as an abrasive agent upon certain surfaces; the lowering in real-estate values where occurring in exceptional quantities; its harmful effect on plant life.

The Pathogenic Effects of Dust have been given extensive study by the medical profession. From what has been said relative to the sources of dust, it is obvious that it is made up of organic and inorganic matter. If germ cultures are prepared from air, bacterial life of different kinds will be found present in quantities which are sometimes startling. Although it is very commonly believed that street dust is full of tuberculosis germs, many bacteriologists are not positive on this point. Dr. T. Mitchell Prudden states that "It is certain that in out of doors, in the country and also in cities whose streets are kept decently clean, there is less danger of harm from the inhalation of germs of consumption or of any other disease, because the constant purifying agency of wind and air currents will either soon sweep away the dust or so largely dilute it that it will be practically free from disease germs, the sources of which are so comparatively limited. If, however, the streets of cities be or are allowed to remain filthy, so that abundant and pretty constant dust clouds are encountered by those passing through them; if the streets are not properly sprinkled before sweeping, either by machine or hand; if ignorant or careless street cleaners are allowed to scatter clouds of dust about them as they sweep or shovel or transport the pulverized filth, the chances of inhalation of dangerous dust particles are proportionately increased. But on the whole, the risk of infection out of doors from dust, even in crowded towns, unless they are notably filthy, is not actually very great." Dust, however, may enhance the contraction of tuberculosis even though it contains no tubercle bacilli. The constant inhalation of dust will irritate the pulmonary organs so as to render them more susceptible to the attack of the tubercle bacilli which are frequently lodged in the mucous membranes of healthy individuals. Various delicate membranes are irritated by the simple mechanical action of the dust, with the result not only of local inconvenience, but many times of general debility.

The membranes of the respiratory organs are susceptible to this influence, especially if a person be asthmatic. The membranes of the eye are also frequently seriously irritated by dust. In the sections where the dust problem has been successfully solved, physicians report a marked falling off in the number of cases of conjunctivitis.

Use of Palliatives. In considering the problem of dust prevention on city streets, it is advisable to classify the public ways under two general heads, business and residential streets, and to further differentiate between residential streets which are narrow, heavily shaded with trees and bordered with residences, and those streets which are more or less open. There is one way and only one way to satisfactorily prevent dust on bituminous, cement-concrete, brick, wood block, and stone block pavements which are subjected to excessive horse-drawn vehicle traffic. That method consists of removing the dung of animals and other street refuse by hand sweeping during the day, mechanical sweeping of the streets at night, which should be preceded by sprinkling, and finally flushing with water to remove fine dust and thoroughly cleanse the surface of the pavement. Under certain conditions dependent upon the amount and character of traffic and the uses to which the street is subjected, it is feasible to omit the mechanical sweeping. It must be realized that it is absolutely impossible economically to remove fine dust by either hand or mechanical sweeping. The use of the so-called dust palliatives and surface treatments on pavements subjected to heavy mixed traffic is entirely wrong in principle, as sanitary conditions require the constant removal of filth from streets, and if this is removed periodically by flushing, the effectiveness of these processes is curtailed. Again, periodical watering of pavements to lay dust throughout the day is fundamentally wrong, as the fine dust which necessitates sprinkling should have been removed.

However, bituminous, cement-concrete, brick, and wood block pavements may be used on streets subjected primarily to motor-car traffic and light horse-drawn vehicle traffic, such as boulevards, open intra-urban trunk lines, etc. In such cases

flushing is not necessarily a prerequisite to cleanliness. Generally patrol hand sweeping throughout the day will be sufficient.

Residential streets may be built with bituminous surfaces or as bituminous pavements dependent upon local conditions. On this class of street the traffic is usually comparatively light from the standpoint of city traffic. If such streets have a surface coat of the proper kind of asphaltic material, the dung of animals and other refuse can be removed by patrol hand sweeping, while the nature of the surface will be such as to absorb fine dust and render the street practically dustless. For macadam streets in poor condition for bituminous superficial treatments or when financial conditions do not render expedient the use of bituminous surface treatments and patrol sweeping, recourse must be had to the use of palliatives. To attain successful results it is necessary that light products having the proper chemical and physical properties should be used in small amounts periodically during the season of dust.

It is evident that the field of usefulness of palliatives is somewhat limited and that this field will grow comparatively smaller in the future as the mileage of good roads and pavements increases, as the economics of construction and maintenance is understood, and as the inherent value of the various methods for the elimination of dust is recognized. As an example of the tendencies outlined may be cited the several yardages of bituminous surfaces and light oil applications as constructed during 1910 and 1911 under the State highway departments of Maine, New Hampshire, Massachusetts, Rhode Island, New York, New Jersey, Pennsylvania, and Maryland. While in 1910, 9,890,400 square yards were treated with light oils, the yardage was reduced in 1911 to 3,765,200. On the other hand, while 2,557,600 square yards of bituminous surfaces were constructed in 1910, the total was notably increased to 8,414,100 in 1911. European engineers appear to appreciate the true value of palliatives as at both the First International Road Congress held in Paris in 1908, and at the Second Congress held in Brussels in 1910, conclusions were adopted to the effect "that emulsions of tars or oils, hygroscopic salts, etc., are really efficient,

but, unfortunately, only for a short time. Therefore their use should be limited to special cases, such as race courses, festivals, processions, etc." In this connection it should be noted that the mileage of roads or streets which are not in a condition suitable for bituminous surfaces is small.

In Europe, however, attention to esthetics has resulted in the use of palliatives where otherwise bituminous surfaces would have been employed. Two illustrative examples will be cited. At the birthplace of the campaign against dust by the use of superficial tarring, namely, in the Principality of Monaco, ordinary watering is used to lay the dust on the boulevards surrounding the beautiful gardens in front of the Monte Carlo Casino. The watering of these surfaces once per hour, in the most scientific manner the writer has ever observed, serves to lay the dust, cool the atmosphere, and furnish a road surface which is in harmony with its magnificent environments. The other instance to be cited is the case of the Bois de Boulogne, which is adjacent to the city of Paris. Its engineer, although allowing one of the avenues to the race course, Longchamps, to be tar coated for experimental purposes, is a firm believer in the use of palliatives for the boulevards of the Bois, inasmuch as the surfaces thus treated are satisfactory from the standpoint of esthetics, and at the same time dustless. The problem of the maintenance of the many miles of these charming avenues is an extremely complicated one, which has not as yet been solved. The avenues in many cases are subjected to traffic which will rapidly disintegrate ordinary macadam treated with any of the palliatives at present on the European market.

Classification. Dust preventives in common use, which may be classified as palliatives, that is, those requiring application with more or less frequency, include water, sea water, salt solutions, calcium chloride, tar and oil emulsions, and certain light oils and tars. As oils and tars are mentioned in the above classification, the distinction between treatments with palliatives and the construction of bituminous surfaces should be borne in mind. Palliatives are those which mitigate, alleviate, or abate the dust nuisance, while bituminous surfaces consist

of superficial coats of bituminous materials with or without the addition of stone or slag chips, gravel, sand, or materials of a similar character. While it is true that the continued reapplication of asphaltic oils and tars may form a bituminous surface, the methods of construction considered under this latter title will be confined to those treatments which ordinarily result in a bituminous surface, efficacious for at least one year.

Water. That water is an efficacious dust layer when properly applied is admitted by those familiar with European practice, especially where this work is under the direction of engineers who supervise the details of the method of application rather than depend upon the whimsical ideas of ignorant and irresponsible drivers of watering carts. From an economical standpoint and when considered from the viewpoint of a road binder, the use of water is limited. It has been demonstrated by many service tests that watering, even when most scientifically administered, will not preserve macadam roads when the traffic consists of rapidly moving motor cars.

Watering is strongly advocated for the purpose of dust laying under modern conditions by S. Whinery, M. Am. Soc. C. E., as follows: * "If it be asserted that street sprinkling as it is generally conducted has not proved satisfactory, it may be replied that it has seldom, if ever, had a fair trial. If the surface of the street were first cleaned, as is the practice before oiling, the objection that water makes the street muddy and sloppy would be removed. If the specifications required that the street surface be kept constantly moist, regardless of whether one daily sprinkling or five were necessary, there would be no trouble from dust. Where the road material is thus kept properly moistened, the wear of the pavement from travel is not greater than where light oil is used, and it is conceded that, as long as the road material is kept well moistened, the peculiar form of disintegration called raveling does not occur.

"As to cost, there is good reason to believe that with careful, intelligent, and economical management, including the restric-

* See Trans. Am. Soc. C. E., Vol. LXXIII, pp. 34 and 37.

tion of the quantity of water used to that actually necessary, it would not much exceed the average cost of the work as now unsatisfactorily done. Ordinarily, at least, it should not exceed 3 cents per sq. yd. per season, and this figure may be safely used for comparison with other methods.

"Summing up the conclusions, it may be asserted confidently that no method of suppressing dust, thus far discovered, is more effective and economical than sprinkling with water. Why not, therefore, drop the fads which are being exploited before the public, and turn attention to developing and perfecting this old method, applying to it the same study, care, and efficient management that are devoted to other lines of municipal work?

"The speaker believes that there is no practical or mechanical difficulty in developing a power sprinkler which will have double the water and speed capacity of the old sprinkling wagon, and which, at one passage along a street 50 ft. wide, will sprinkle the whole surface effectively from curb to curb. Proper specifications and rigid supervision would accomplish a revolution in the work, both from the standpoints of efficiency and economy.

"In a great majority of cases, the common objection that sprinkling the country highways is impracticable because of the frequent absence of a water supply, may be overcome by temporarily installing suitable power pumps at streams and ponds. Where this is not practicable, high-speed power sprinklers would make it possible to obtain the water from comparatively distant sources without increasing the cost of the work materially. With proper watering, the durability of country roads during dry seasons would be increased so much that the sprinkling might almost result in a profit."

The following notes by R. A. Meeker relative to the use of water on state highways are of value.* "Water has been used on some New Jersey roads, but in a peculiar manner. In the summer the water was applied after sundown, not to lay the dust, but to retain the cementing properties of the stone. A

* See Trans. Am. Soc. C. E., Vol. LXXIII, p. 42.

stone road will very often attain a temperature of 110° Fahrenheit and water sprinkled on it during the day simply evaporates, without doing any good. To overcome this objection some roads have been sprinkled at night, with very good results. It is true they are somewhat dusty after midday, but they do not disintegrate or break to pieces, and the fine material is not blown off."

Cost Data. Mr. Whinery gives the following information relative to the cost of street sprinkling with water.*

"The cost of efficient street sprinkling is difficult to determine satisfactorily from the data available. Where referred to at all in municipal reports, the necessary conditions to enable one to deduce reliable figures of unit cost are usually wanting. These reports indicate that the cost, exclusive of water, ranges from less than 1 cent to 3½ cents per square yard for the watering season, which usually extends from May 1 to October 15. The number of square yards sprinkled once is seldom given, and as the number of times sprinkled per day or per season varies greatly in different cities, and on different streets in the same city, and as there are other varying conditions to be taken into account, it is not possible to get at the basic unit cost from the available records. It is practicable, of course, to estimate the theoretical cost very closely, but such estimates are less satisfactory than actual data from experience.

"The statistics available seem to indicate that, exclusive of the cost of the water, the average cost per square yard per season is about 2 cents. The quantity of water reported as used is as variable as the cost of applying it. The figures vary from 20 to 70 gal. per sq. yd. per season. Probably 45 gal. is a fair average, and, at $90 per 1,000,000 gal., the cost for water per square yard per season would be about 4/10 cent, making the average total cost less than 2½ cents per sq. yd. per season. In Boston, where the accounts are now kept with care, the quantity of water used in 1909 was less than 25 gal., and the total cost 2.1 cents per sq. yd. per season. In the suburban city of East

* See Trans. Am. Soc. C. E, Vol. LXXIII, p. 34.

Orange, for the same year, these figures were, respectively, 58 gal. and 2.82 cents, including the cost of water."

Sea Water. The use of salt water obtained from the sea has not been developed sufficiently to establish its value and rating as a dust palliative. It has been tried in a number of instances in coast towns and cities, usually being applied with the ordinary watering cart. In one instance it was found that in dry weather it formed a hard salty scale, while in wet weather the mud contained so much salt that it injured the iron and varnish of vehicles. John A. Brodie, City Engineer of Liverpool, in 1911 stated that "at Blackpool sea water is used almost exclusively for street watering, as it is found that sea water is about three times as effective in preventing dust as fresh water, and, if properly applied, has no injurious effects on the road surfaces. The Blackpool practice is really to wash (not sprinkle) the surfaces of all the principal streets, both horse and manual brushes being freely used in removing all loose matter from the street surfaces and washing them into the street gullies. A further annual cost of about $45 per mile of streets is incurred in street watering only."

Oil and Water. A method of mechanically mixing oil and water without the solvent has been devised. It consists of using a cart with two tanks, one containing the oil or tar and the other containing the water. The two substances are led through pipes into a box where they are thoroughly mixed by a set of rapidly whirling blades, which also force the mixture onto the road in the form of a spray, the idea being that the water will evaporate and leave the oil in a fine film.

Calcium Chloride. This material is a by-product in the ammonia-soda process of manufacturing common washing soda and in other industrial processes. It is shipped in granulated form in air-tight steel drums. Calcium chloride is used in two ways in connection with dust-laying on roads: first, by the "wet" method and, second, by the "dry" method. When applied dry to the road surface, see Fig. 96, a special distributing apparatus should be employed. (Cost of 1-horse machine with spread of 5 ft., $40; 2-horse machine with spread of 10 ft., $47.) About

1½ lb. should be used for an application per square yard. Usually two applications per season in the North will give good results. When applied wet, it is recommended that the calcium chloride should be dissolved at the rate of 1 lb. to 1 gal. of water, using about 1/3 gal. of solution per sq. yd. For the application of the solution ordinary watering carts are generally used. The usual

FIG. 96. Application of Calcium Chloride by the "Dry" Method.

method is to distribute in two applications along the center of the street and one at the sides. To secure freedom from dust about ten applications should be used per season in Northern States.

The most scientific work which has been done with calcium chloride was that carried on by a Committee of Judges of the Roads Improvement Association of England in 1909 and 1910. After exhaustive experiments the following conclusions were deduced in the fall of 1909 and the spring of 1910 respectively: "We are of opinion that the results of the tests of calcium chloride applied in granular form by the 'dry' method have shown that it is a very effective dust layer, and, provided no ill effects are experienced in winter as a consequence of the treatment, we are of opinion it is a cheaper and preferable process to that of street watering, which, as now carried out, is undoubtedly very injurious

to macadamized roads; that the treatment has the ill effects of causing, during the winter months, an abnormal quantity of sticky mud, a decided tendency to licking up, and a disintegrating action upon the macadam surface. Notwithstanding this, we are of opinion that the process is probably not more injurious to macadamized roads than the excessive watering now demanded by the public effectively to lay the dust."

Cost Data. Typical costs per square yard of dust-laying with calcium chloride follow:

Metropolitan Park Commission, Mass., season 1908, 2.5 cents sq. yd.; 1909, 1.8 cents; 1910, 3 cents; Pennsylvania, 3 to 4 cents; city of Boston, 1.6 to 4.2 cents; District of Columbia, 2.1 cents.

At Watertown, N. Y., in 1911 calcium chloride was applied dry from a lime spreader. The streets were first swept by hand. The cost of material, including freight and haul, was $2.85 per drum. About 13,700 feet were treated, 20 ft. wide, using 100.5 drums of calcium chloride at an estimated cost of 1.33 cents per sq. yd. On eleven sections treated, average costs were: Sweeping .14 cent per sq. yd.; hauling and spreading .14 cent per sq. yd.; foreman .05 cent per sq. yd. Total cost on 19 sections averaged 1.69 cents per sq. yd.

In Onondaga County, N. Y., calcium chloride was used in 1911, there being three applications as follows: 1 lb. per sq. yd. on June 1, ¾ lb. on July 15, and ¾ lb. on September 1. The total cost was 1.87 cents per sq. yd., including application and material.

In Milwaukee and Waukesha Counties, Wis., 75 tons of granulated calcium chloride were used. On one section a total of 2½ lbs. per sq. yd. was applied in two applications three weeks apart. On a second stretch 2½ lbs. were used in two applications six weeks apart. The cost in the second instance is stated to have been 2.29 cents per sq. yd. for the season.

Emulsions. Palliatives belonging to this class are made by the addition of some saponifying agent to water, which, forming a chemical solution, renders it readily miscible with the oil. They sometimes contain a deliquescent material as an aid in retaining moisture. Their use is common where a light palliative

is sought. Alkalies such as potash, soda, ammonia, crude carbolic acid, and various soap solutions are the mediums most commonly used with asphaltic or paraffin oils. Among the numerous processes are: casein added to tar oil; water lyes from wood-pulp factories; fat or grease from wool scourings, emulsified with either deliquescent salt solutions or creosote; an oil emulsion containing a deliquescent salt; waste sulphite cellulose liquor; waste molasses solutions; and mixtures of saccharine and lime. Tar emulsions are used to a small extent in this country. Distribution is usually made with an ordinary watering-cart on the unprepared surface, although better results may be obtained by using some type of pressure distributor. Sometimes a light sand coat has been added, but as a rule the surface is left uncovered. A typical emulsion (Wickes) consists of 5 percent resin soap added to 30 percent water at 50 degrees Centigrade. The mixture is thoroughly agitated and 65 percent oil added. A 20 percent solution mixed at 32 degrees Centigrade was first used, and for retreatments 5 to 10 percent solution. In Boston a 16 percent solution has been used first with 5 to 10 percent solution for retreatments. According to the Superintendent's report for the year 1910, 5,845,178 sq. yds. of roadway were treated with emulsions in the ten districts of Boston. The average number of times treated was 7.788, making a total area of 43,479,329 sq. yd. treated once. The average cost of one treatment was .223 cent or 1.656 cents for the season. A total of 1,565,302 gals. of emulsions was used, or .2651 gal. per sq. yd., this emulsion having about three times its volume of water added before application. The period of application was from about March 15 to November 20.

Light Oils and Light Tars. In this group of palliatives may be included certain vegetable oils, paraffin and asphaltic petroleums, tar oils, water-gas tars, coal-gas tars, and a large variety of proprietary compounds. Light oils were employed in 1898 in Los Angeles and Algeris for the purpose of laying the dust. Their use has developed rapidly in America due to the large supply available, while, as the price of oil is comparatively high in Europe, very little oil has been used. The tendency in Europe

has been, for the past five years, to discard all types of palliatives, so that only a small amount of what is known as light tar is employed, the practice being to construct bituminous surfaces which will be efficacious for at least a year. There is sometimes enough binding base to cement the particles, and such materials are preferable, as a number of applications result in an accumulation of binding material at the end of a season.

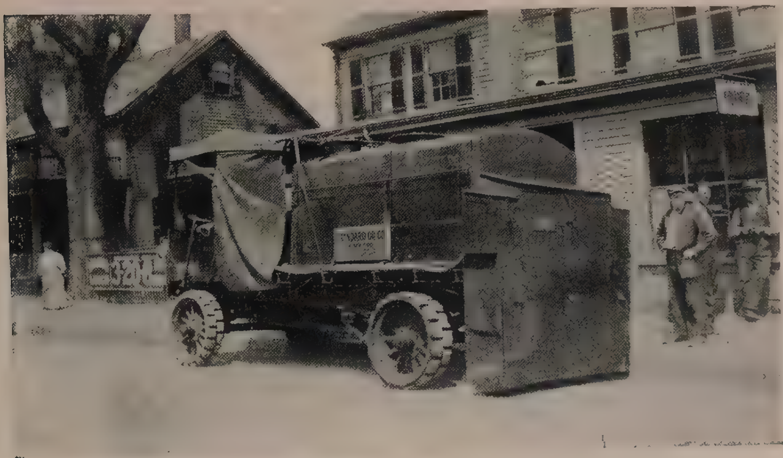

FIG. 97. Pressure Distributor Used for Applying Light Oils.

They are fairly efficient, but should not be applied in too great an amount, as a soft greasy surface will result. Heavy rains may either cause washing or an oily disagreeable mud and pools of oily water. For reasons of economy the material is usually applied cold, using ordinary sprinkler carts or distributors, of either the gravity or pressure type. In order that this class of palliatives should be distributed economically and satisfactorily, pressure distributors should be used which are equipped with suitable hoods to protect pedestrians and property from the attendant fine spray and which are capable of distributing the material in as small amounts as ⅛ of a gallon per square yard. The accompanying photographs, see Figs. 97 and 98, show the distributor of the type described and an application of a light oil. If this method of distribution was employed, few would be the

complaints of ruination of clothes and house furnishings, filthy streets, and disagreeable odors.

As illustrative of some of the physical and chemical properties of a typical light oil and a light tar which have been used as dust palliatives, the following analyses are given.

LIGHT OIL

Specific gravity at 25° C.	0.92
Solubility in carbon disulphide	99.9 %
Fixed carbon	5.3 %
Loss at 170° C. for 5 hours	26.8 %
Viscosity Engler 50 c.c. at 25° C.	48.
Solubility in 88° B. naphtha	9.8 %

LIGHT COAL TAR

Specific gravity at 25° C.	1.16
Free carbon	9.8 %
Distillation to 105° C.	6.0 %
Distillation 105° to 170° C.	1.2 %
" 170° " 225° C.	6.9 %
" 225° " 270° C.	8.2 %
" 270° " 300° C.	7.2 %
Pitch	70.5 %

It has been claimed in some quarters that by the use of light oils, macadam roads could be preserved under high-speed motor-car traffic. This fallacy has caused a large waste of public funds in many cases, since the macadam has not only begun to disintegrate within two to three weeks after the application of the oil, although the effectiveness of the application as a dust-layer was apparent for six weeks, but the road surface was left wholly unprotected during the trying winter and spring months. If properly applied, light oils are effective for about six weeks, but to apply them after November 1 in the Northern States is to insure muddy, greasy surfaces during a part of the winter.

In 1909 over 75 miles of the State highways of Rhode Island were oiled. The quantity of oil used per square yard was 0.2 gallon, applied at a labor cost of from 0.1 to 0.3 cents. As the oil cost 3.5 cents per gallon, the average cost per application was about 0.9 cents per square yard. The following bids were received by the City of Providence for oiling in 1911. The work was supposed to begin about April 10 and be so

continued as to render the streets dustless until November 1. The Texas Company, bidding on road oil in tank-car loads, see Fig. 99, submitted a bid of 3.65 cents per gallon. The Daniels Road Oiling Company of East Providence bid 1 cent per square yard on spraying with road oil, 4 cents on oiling with road oil for the entire season, 3 cents per sq. yd. for oiling with emulsion oil for the season. The Standard Oil Company of Boston bid

FIG. 98. Road Surface Showing Uniform Application of Light Oil.

1¼ cents per square yard for spraying with road oil for three treatments, 3½ cents per square yard for spraying with road oil for the season, 4.15 cents per gallon on road oil in tank cars, and 5 cents per gallon for emulsion in tank cars. In the Borough of Richmond the following costs per square yard are characteristic of this class of work: 1908, light oil, 3.3 cents per square yard; light tar, 4.2 cents; 1909, light oil, 4.2 cents; light tar, 3.2 cents; 1910, light oil, 2.5 cents, light tar, 3.8 cents. Fig. 100 shows the storage tank for light oil located in the municipal yard of Springfield, Mass. One result of its erection was to secure lower prices on road oils as the supplying company was thereby saved tank-car charges, since immediate delivery was assured.

The results of the use of certain tars and oils necessarily come on the border line between a palliative treatment and

the construction of a bituminous surface. H. C. Poore, Jun., Am. Soc. C. E., describes the use of a grade of tar of this character in Massachusetts as follows:* "The general method of application was as follows: After the surface had been thoroughly swept, thin refined tar (½ gal. per sq. yd.) was applied by a pressure-tank wagon, sprinkler wagon, or by some form of hand-dipper After a few hours the surface was covered with grit.

Courtesy of the Texas Company.

FIG. 99. Oil Tank Car.

Both pea stone and fine gravel were used, and 1 cu. yd. of material usually sufficed to cover 120 sq. yd. of surface. Where the entire road or only a portion could be closed and guarded for 24 hours after spreading, the coating of grit was not always necessary. The average cost of this work in Massachusetts was from 3 to 5 cents per sq. yd., including all materials and labor. With this treatment, a macadam or gravel road in fair condition will become hard and free from loose grit in the course of about 10 days. The surface then remains in condition for the season, and, with a retreatment of ¼ gal. per sq. yd. in the fall or following spring, will be in good condition for a second year. The second treatment may be applied at a greatly reduced cost. A very efficient and economical way of applying a thin tar for dust prevention is by using 500-gal. tank wagons, fitted with

* See Trans. Am. Soc. C. E., Vol. LXXIII, pp. 40 and 41.

auxiliary pressure tanks for blowing out the material through suitable nozzles under pressure. The use of a hose with a nozzle is a very practical method of distributing all light materials, and when they are delivered by pressure, the spreading of a ¼-gal. coat to the square yard is easily accomplished. Two applications of this quantity of material during the first year, followed by one coat during the second year, will suffice to keep the surface of a macadam road in first-class condition."

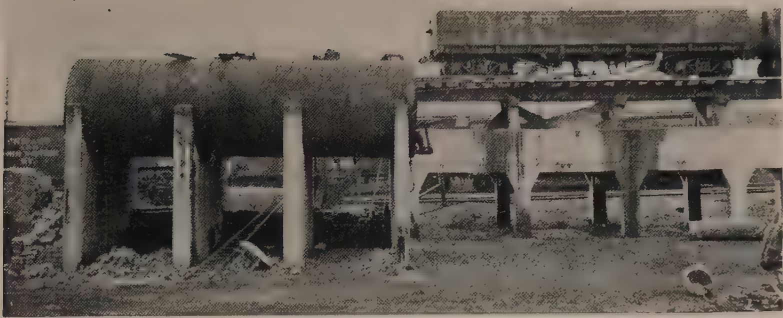

FIG. 100. Storage Tank for Light Road Oils.

The use of light asphaltic oil of this type on park roads of Washington, D. C., is described by Col. Spencer Cosby, M. Am. Soc. C. E., as follows:

"All ruts and holes in the surface of the road are first repaired by cleaning out the cavity, filling it with coarse stone which is covered with a coating of hot, heavy, asphaltic oil, then sprinkling a light coat of screenings over the oil, and finally compacting the mass by ramming. When all holes have been repaired, the surface of the road is thoroughly cleaned with rattan brooms, care being taken to remove all loose materials and caked dirt or dust so that the stone forming the wearing surface of the road shall be exposed and clean. When the road is entirely free from moisture, and during warm, dry

weather, if possible, a light asphaltic oil is spread without being heated over its surface by means of special sprinkling wagons. One-third to one-half gallon of oil to the square yard usually forms this first application. To allow it to penetrate into the surface, the road is closed to traffic for at least forty-eight hours after the first application. At the end of this time the surface of the road is covered with a thin coating of clean, coarse, sharp sand or broken-stone screenings, free from dust; it is then rolled and traffic allowed to go over it. A cubic yard of sand or screenings usually covers from 75 to 125 square yards of road surface. In this climate and under the conditions of traffic obtaining on our park roads, the oiling treatment described above keeps the surface in excellent condition for a year. It is never dusty and is only muddy when for a few hours after a heavy thaw the skidchains of automobiles tear up the surface. The subsequent passage of automobiles without chains soon irons out the roadway. At the end of the year the surface of the road is again thoroughly cleaned, from one-fourth to one-sixth of a gallon of oil to the square yard under normal conditions is spread over it, and the road closed for forty-eight hours and covered with sand or screenings as before. This treatment is continued from year to year.

"Instead of handling the oil in barrels, we have found it much cheaper to buy it delivered in tank cars, from which it is unloaded into the sprinkling wagons. A pressure-tank wagon was used to advantage for the first application of oil to the road surface, but ordinary sprinkler wagons with an oil-distributing attachment and a squeegee fixed behind the distributor were found more economical and equally efficient in spreading the oil the second year. To insure coating all parts of the road with an oil layer of uniform thickness, men with stiff brooms followed the sprinkler.

"The following are the specifications under which we have been purchasing asphaltic oil for the surface treatment of park roads:

1. The oil shall be a viscous fluid product, free from water and showing some degree of adhesiveness when rubbed between the fingers.

2. It shall have a specific gravity of not less than 0.940 at 25° C.

3. It shall be soluble in carbon bisulphide, at air temperature, to at least 99 percent and shall show not over 0.2 percent of inorganic matter insoluble.

4. It shall contain not less than 3 percent, nor more than 10 percent, of bitumen insoluble in 86° paraffin naphtha at air temperature.

5. When 240 c.c. of the oil is heated in an Engler viscosimeter to 50° Centigrade and maintained at this temperature for at least three minutes, the first 50 c.c. shall flow through the aperture in not less than ten minutes, nor more than twenty minutes.

6. When 20 grams of the material are heated for five hours in a cylindrical tin dish approximately two and one-half inches in diameter by one inch high, at a constant temperature of 163° Centigrade, the loss in weight by volatilization shall not exceed 20 percent. The residue should be decidedly sticky.

7. Its fixed carbon shall be not less than 3.5 per cent.

"The following table shows the cost from July 1, 1910, to June 30, 1911, oil or tar being the material used:

No. of road	Material used	Area of road, sq. yds.	Sq. yds. treated per gal.	Cost of oil and applying per sq. yd., cents	Remarks
1	Oil	7,500	3.26	2.8	2d and 3d applications
2	"	19,000	4.75	2.2	2d application
3	"	3,400	3.40	2.7	"
4	"	8,600	12.23	1.2	"
5	"	25,000	5.00	2.1	"
6	"	43,560	4.11	2.2	"
7	"	19,450	5.72	1.9	"
8	"	4,000	11.43	1.3	"
9	"	1,680	1.68	4.6	1st application
10	Tar	11,400	1.90	4.4	"
11	"	1,500	2.30	3.8	"
12	"	3,560	2.23	3.8	"
13	"	7,740	3.00	3.1	"
14	"	8,100	3.39	2.8	"
15	"	2,000	2.38	3.8	"
	Total	166,490	Av. 3.83	Av. 2.5	

Cost of labor per square yard....................	0.8 cent
Cost of oil per gallon...........................	6.5 cents
Cost of tar per gallon...........................	6.8 cents
Average cost in past years of watering roads, per square yard............................	3.2 cents

"In the above table the cost of the sand or of the stone screenings used after the application of the oil has not been taken into account, as it is considered part of the cost of repair of the road.

"It is only fair to add that one reason why our park roads have been in so much better condition since we started the use of the surface treatment I have described is that we have abandoned the old method of repairing them once a year and now have a system of regular and frequent inspection and repair. Supplies of broken stone, screenings, oil, and tar are kept constantly on hand in the vicinity of the roads, and holes and ruts are repaired as rapidly as they develop, usually before they have become large enough to be noticeable to traffic. We have practically no hills on our roads, so the greatest amount of repair work has to be done on the few sharp curves. The roads are also kept clean, being swept by hand sweepers at fairly frequent intervals."

Although there is a large variety of proprietary palliatives on the market, they will not be considered, first because they are of more or less transitory character, and furthermore the fundamental principles underlying the use of palliatives have been fully covered in the foregoing discussion.

The various types of gravity and pressure distributors suitable for the distribution of the various classes of palliatives described will be considered in the chapter on Bituminous Surfaces.

CHAPTER XII

BITUMINOUS SURFACES

As stated in the chapter on Bituminous Materials, bituminous surfaces consist of superficial coats of bituminous materials, with or without the addition of stone chips, gravel, sand, or materials of a similar character. While it is possible to build up a bituminous surface on a macadam or gravel road by the repeated application of palliatives of certain types, the methods of construction referred to in this chapter will be devoted entirely to surfaces formed by one application which, under traffic conditions for which they are suitable, will have a life of at least one year. Bituminous surfaces are used principally on macadam and gravel roads, on bituminous and cement-concrete pavements, and to a certain extent on brick and wood-block pavements. This chapter will be devoted to a consideration of the method of construction and maintaining bituminous surfaces on broken stone and gravel roads, while bituminous surfaces on bituminous macadam pavements, bituminous concrete pavements, asphalt-block pavements, cement-concrete pavements, brick and wood-block pavements will be treated in the chapters devoted to the several pavements.

Development. As early as 1871, Francou of Auch, France, actually employed tar as a surface treatment in a few trials. His method was to spread the tar cold on the surface and then set fire to it in order to harden the surface. Christophle in 1880 used tar on a road at Saint-Foy, and in 1888 another experiment was tried with this material at Saint Gaudens by Lavique. In 1896 Girardeau conceived the idea of applying hot tar to a road surface by observing the better results obtained when a cold tar application was acted upon by the heat of the sun. His experiments were the most extensive up to this time. It was not until 1901, however, that systematic experiments were carried

out. Such experiments were started by Dr. Guglielminetti at Monte Carlo, Geneva, and Nice, using coal tar and brushing the same into the road surface. The campaign in Europe against dust and the deterioration of road surfaces, caused primarily by motor-car traffic, was thus inaugurated by Dr. Guglielminetti, who since that time has organized "Leagues Against Dust" in many European countries, and with unswerving enthusiasm has worked continually to interest officials and engineers in the necessity for the suppression of dust. The results of his successful experiments with superficial tarring at Monaco were published throughout all Europe. In the following year trials were carried out at Champigny by the engineers of the Department of Roads and Bridges of France. In the 1903 report on these trials, the French engineers formulated all the basic principles of superficial tarring. By this time the success of superficial tarring was well established, and its continued use in Europe has borne out the wisdom of those who first conceived the idea.

It might be said that dust suppression was the main cause of the development of the method of surface treatment. While in Europe it led to superficial tarring, in this country the first trials of this method were made with light oils. Oil was first used for this purpose in 1894 at Santa Barbara, California. Further trials were made in 1898 and oils were used to a very slight extent in different parts of the country up to 1905. A few similar trials were made in Europe with indifferent success with oils procured from that country. After 1905 the use of oils as a dust palliative rapidly increased in the United States. As a general rule they were light in character and could be applied cold. At the present time the use of the lighter oils is diminishing and a heavier asphaltic oil is being used for surface treatments which not only lays the dust, but also serves as a protection to the road surface. Surface tarring has been used in this country since 1906.

Some idea of the development in the use of bituminous surfaces in the eastern part of the United States may be gleaned from the following figures covering construction under the State Highway Departments of Maine, New Hampshire, Massa-

chusetts, Rhode Island, New York, New Jersey, Pennsylvania, and Maryland. In 1908, 57,700 square yards of bituminous surfaces were constructed using tars and tar-asphalt compounds, and 239,500 square yards using medium and heavy asphaltic oils and asphalts. In 1911, 433,700 square yards were constructed using tars and tar-asphalt compounds and 7,980,400 square yards with medium and heavy asphaltic oils and asphalts. In Europe bituminous surfaces have been employed since the early part of the twentieth century. In 1910 over 92,682,400 square yards of road were superficially coated with bituminous materials. The present extensive use of this type of construction is indicated by the statement of H. P. Maybury, M. Inst. C. E., that in the County of Kent in 1911 over 5,000,000 square yards of bituminous surfaces were built, using 823,760 gallons of tar.

Bituminous Materials

The different kinds of bituminous materials used are asphaltic oils, asphalts, crude and refined water gas tars, crude and refined coal gas tars, combinations of refined tars, and combinations of refined tars and asphalts. The sources, manufacture, and methods of determining the physical and chemical properties of these materials have been considered in Chapter X.

There has been noted a growing objection to the use of materials, for the construction of bituminous surfaces, which require from two to six weeks to set up to such an extent that tracking will not occur. By "set up" is meant that condition of the surface under which there is practically no tracking of the bituminous material or surface coat. During 1911 and 1912 several materials have given satisfactory results from this standpoint. These include certain refined coal tars and water-gas tars, combinations of asphaltic materials and refined tars, and certain asphaltic materials.

It has been found that, within twenty-four to forty-eight hours, bituminous surfaces constructed with the foregoing materials, using ½ gallon per square yard and a thin covering of sand or chips, have set up so that no tracking is noticeable.

Tar and tar-asphalt compounds have long been recognized as having this property, but asphalts and asphaltic oils suitable for bituminous surfaces, from the above standpoint, have been difficult to procure.

In order to illustrate some of the methods adopted in writing specifications for bituminous materials used in the construction of bituminous surfaces both in the United States and abroad, and also to give a general idea of the properties of some of the materials which have been employed, the following specifications and analyses are given. It must always be borne in mind that illustrative examples, such as follow, are not to be adopted blindly. Specifications and analyses vary to a wide degree, dependent upon the local conditions in each case and the nature of the materials available.

Coal Tar. The specifications adopted by the Road Board of England are quoted, as it represents the consensus of opinion of many prominent British engineers who have used tar for many years for the superficial treatment of macadam roads.

"The tar shall be derived wholly from the carbonization of bituminous coal, except that it may contain not more than 10 percent of its volume of the tar (or distillates or pitch therefrom) produced in the manufacture of carbureted water gas.

"The specific gravity of the tar at 15 degrees Centigrade (59 degrees Fahrenheit) shall be as nearly as possible 1.19, but in view of the great variation in specific gravity of the tars produced in various parts of the country, the specific gravity may be as low as 1.16, or as high as 1.22, provided that in other respects it complies with the provisions of the specification.

"The tar shall be commercially free from water, *i.e.*, it shall not contain more than 1 percent by volume of water or ammoniacal liquor, which water or liquor (if present) shall not contain more ammonia, free or combined, than corresponds to 5 grains of ammonia per gallon (=70 milligrammes per litre) of the tar.

"On vigorous agitation for a quarter of an hour, with twenty times its volume of water at 21 degrees Centigrade (70 degrees Fahrenheit) the tar shall not impart to the water more than 5

grains of phenoloid bodies, reckoned as phenol, per gallon of water (=70 milligrammes per litre).

"The provisions in the following clauses apply to tar supplied direct from gas works.

"The tar shall be solely the natural by-product of the manufacture of illuminating gas (coal gas with or without admixture of carbureted water gas), and shall have been subjected to no other or further treatment than may be necessary for the abstraction of water or ammoniacal liquor and light oils.

"On distillation the tar must yield: below 170 degrees Centigrade not more than 1 percent, and between 170 degrees Centigrade and 270 degrees Centigrade not less than 16 percent and not more than 26 percent of distillate (exclusive of water).

"The free carbon shall not exceed 16 percent of the weight of the tar.

"The provisions in the following clauses apply to tar supplied from tar distilleries.

"On distillation the tar must yield: below 170 degrees Centigrade not more than 1 percent and between 170 degrees Centigrade and 270 degrees Centigrade not more than 26 percent of distillate (exclusive of water). The distillate shall remain clear and free from solid matter (crystals of naphthalene, etc.) when maintained at a temperature of 30 degrees Centigrade for half an hour. The distillation shall be continued to 300 degrees Centigrade, and the residual pitch thus obtained shall not amount to more than 73 percent of the weight of the tar.

"The free carbon shall not exceed 16 percent of the weight of the tar.

"The temperature during distillation shall be taken by a thermometer of which the bulb shall be opposite the opening to the side tube of the distillation flask, and the quantities of distillates and free carbon shall be stated in percentages by weight of the portion of tar submitted to distillation.

"A tar prepared by simple dehydration fulfilling the provisions of this specification may be used with satisfactory results

in most cases, but tars from which the naphthalene has been extracted are superior for the purposes of surface tarring."

Water Gas Tar. Prévost Hubbard, Assoc. Am. Soc. C. E., states that the water gas tar, the analysis of which is given below, has been used in the construction of a bituminous surface on a macadam road. The analysis was made in accordance with the methods described in Bulletin No. 38 issued by the U. S. Office of Public Roads.

REFINED WATER GAS TAR

Specific gravity	1.158
Float test at 32° C.	2 min. 11 sec.
Float test at 50° C.	52 sec.
Bitumen soluble in carbon disulphide	99.06%
Organic matter insoluble	0.88%
Ash	0.06%
	100.00%

DISTILLATION

Water	0.0 %
Oils to 110° C.	0.0 %
Oils 110° C. to 170° C.	0.3 %
Oils 170° C. to 270° C.	5.0 %
Oils 270° C. to 315° C.	14.3 %
Pitch residue (fairly soft)	80.2 %
	99.8 %

Construction

Preparation of Road Surface. Before constructing a bituminous surface on a broken stone or gravel road, all depressions, pot holes, ruts, or other irregularities should be completely eliminated by filling the same with bituminous-coated stone so that the whole road surface is even. All surplus dust must be removed from the surface by the use of horse sweepers and fine bass brooms or with coarse fibre brooms and fine bass brooms, see Fig. 101. Thorough sweeping should result in the exposure of the stone of the upper course, but without breaking the bond. In the preparation of a macadam or a gravel road for the application of bituminous material it will be apparent that

the method of originally constructing the road will have an important bearing upon the character of the bituminous surface. For instance, if the practice of French engineers in using large-size stone varying from an inch to two and one-half inches in longest dimensions for the top course of a macadam road is followed, and this stone is hard and tough in character, the desired surface, see Fig. 102, can be easily secured. The large

FIG. 101. Coarse Fibre Broom (left) and Bass Fibre Broom (right).

stones are exposed and the layer of dust, so characteristic of macadam surfaces composed of small stone, has thus been practically eliminated. Not only is this feature of construction of the utmost importance from the standpoint of the formation of a satisfactory bituminous surface, but the maintenance of these surfaces is much simplified and more economical in that, if the bituminous surface wears away in spots, the large stones will of themselves generally have sufficient stability to withstand the effects of traffic until retreated. Evidently this is the ideal character of surface to receive a coat of bituminous material, as the adhesion resulting will, of course, be excellent. On the other hand, if the top course of a macadam road has been constructed of the run of the crusher from dust to inch material, it will be very difficult to secure a clean surface. It

is much more difficult, not only to prepare the surface of this type satisfactorily, but the chances of failure are much greater, due to the probability of there being considerable detritus between and on the stone, some of which may be damp, although to the eye apparently bone dry.

When the bituminous material is applied the surface should be bone dry and free from dust. If certain asphaltic oils are used and the surface is slightly damp when the material is

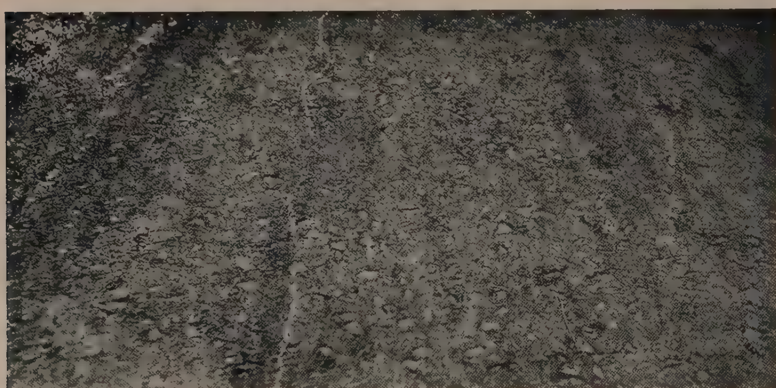

Fig. 102. Surface of Macadam Road Showing Large Broken Stone.

applied, some engineers believe that better results may ensue because, in their opinion, a more even distribution and adhesion of the material are obtained than when the surface is dry. The explanation offered by Clifford Richardson, M. Am. Soc. C. E., in support of the contention that oil adheres better to the surface of a watered macadam road than to a dry road is of interest.*

"There is always a slight coating of dust adhering to the surface stone, which prevents adhesion. If, however, the surface is sprinkled before the application of the oil, it converts this dust into a paste. The dust is the detritus of the rock, and, like clay, it is more or less colloidal. The result is that the dust in this condition will emulsify with the oil when the latter is applied to the surface and will mix with it so readily that the bitumen will come in contact with the rock, and, after the evaporation

* See Trans. Am. Soc. C. E., Vol. LXXV, p. 561.

of the water, will adhere perfectly. Clay and water will mix with any kind of asphaltic oil, and with the greatest facility. A great deal of it has been used on roads in Germany for distributing oil as an emulsion. The clay and water are mixed with the oil, put into the watering-cart, and sprayed on the road."

Application of Bituminous Material. Distribution is accomplished by two general methods. In one the laws of gravitation are utilized, in the other mechanical pressure is employed. Under the first method the following mechanical appliances are used: pouring cans, hand-drawn distributors, tanks equipped with flexible hose, and machines with horizontal distributing devices with and without attached brushes. Pressure distribution is accomplished by a pressure tank to which is attached flexible hose provided with one or more nozzles and by machines with horizontal distributing pipes fitted with suitable nozzles.

Gravity vs. Pressure Distribution. In connection with the application of the bituminous material, the use of gravity distributors has not been developed to its fullest extent in America in that the use of mechanical brushes or the brushing of the material into the road by hand brooming has never been adopted extensively. The advantages claimed for pressure distributors are more even application, the ability to distribute a small amount per square yard, and the better adhesion obtained. It should be borne in mind, however, that by brushing after gravity distribution, it is possible to distribute uniformly one-quarter to one-fifth of a gallon per square yard of many of the bituminous materials used for the construction of bituminous surfaces. In some cases the adhesion of the material to the road metal is as good and the forcing of the bituminous material into the crevices of an exposed surface is much better when accomplished by hand brooming than when the material is applied under pressure.

Major W. W. Crosby's opinion relative to the effectiveness of pressure distribution is shown by the following quotation:* "The adhesion of a bituminous material to a stone or concrete

* See Trans. Am. Soc. C. E., Vol. LXXV, p. 563.

surface may be increased by the use of a pressure distributor. The pressure machine seems to act like the cement gun when used on dirty steel, because the sand blown through the gun against the steel cleans off the dirt and allows a good adhesion of the cement. In the same way, the pressure distributor seems to obliterate the dust film between the stone or concrete and the pitch, which nullifies the adhesiveness of the latter; at least, where it has often been difficult to obtain adhesiveness under a gravity application, the results have been entirely satisfactory where the same materials have been applied under pressure."

W. H. Fulweiler, Assoc. M. Am. Soc. C. E., has presented the following discussion relative to pressure distribution:* "If a heavy pressure is used, it will apparently atomize the bituminous material, and when this happens, it ceases to strike the road with that necessary, directional velocity which blows the dust away as the material is distributed. The nozzles of the machine with which the speaker is most familiar are similar to the flat-top Bray burners used for illuminating gas. As they leave this nozzle the two streams of material impinge on each other and form a flat sheet or spray of material at right angles to the original plane of the two streams. The amount of pressure used modifies the shape of the spray. As the pressure is increased the sheet of material strikes the road with increasing force, and blows the dust from the surface very effectively. If the pressure is increased still further, a point will be reached that will cause the lower edges of the spray to open or separate, and at this point the material has become atomized. From this point a further increase in pressure will more completely atomize the material until finally it is all in that condition as it leaves the nozzle, and reaches the road in minute drops rather than a solid sheet, actually defeating the desired scrubbing action on the surface."

Amount of Bituminous Material. As a general rule from ¼ to ½ a gallon per square yard is used in one treatment. In some cases, however, as small an amount as ⅛ of a gallon per square yard is used. The amount applied per treatment will

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* See Trans. Am. Soc. C. E., Vol. LXXV, p. 568.

depend upon the kind of bituminous material, the character and condition of the surface, and the details of the method of application.

Top Dressing. The superficial coat of bituminous material is usually covered with either coarse sand, fine gravel, or screened stone chips varying from ⅛ of an inch to ½ an inch in longest dimensions. The amount of sand, screened stone chips, or

Fig. 103. Warren Brothers Hand-drawn Sand or Stone-Chip Distributor.

gravel used per square yard depends upon the quantity and kind of the bituminous material. From 7 to 35 pounds per square yard have been used. When heavy asphaltic oils are used, the covering of mineral matter is an absolute necessity. With some grades of tar, however, satisfactory results have been obtained by omitting the covering of mineral matter. This practice is common in some sections of England where the traffic can be kept from the road until the tar has set up. Although it is not necessary under all conditions to roll the top dressing, the bituminous surfaces thus finished are usually materially improved. Figs. 103 and 104 show two machines used for distributing top dressing. Both machines operate on the same principle, one being hand drawn, the other being hauled by

a pair of horses. While passing over the coat of bituminous material the mineral matter falls on a revolving cone beneath the body of the wagon and is thus uniformly spread over the surface.

Specifications. The following abstracts from general directions for surface tarring recommended in 1911 by the Road Board of England not only present many essentials of detail

Courtesy of Charles Hvass & Company.

Fig. 104. Horse-drawn Sand or Stone-Chip Distributor.

construction, but also give a comprehensive description of English methods which have proved satisfactory.

"Surface tarring may be advantageously applied either to an old road surface in good condition or to a new surface after it has been consolidated and dried, but the tarring should never be carried out unless the road is thoroughly dry.

"If there are any depressions, pot-holes, waves, grooves, or other irregularities, these should as far as practicable be made good before tarring is commenced, so as to provide an even surface.

"Painting and spraying machines get through the work of tarring more rapidly than application by hand, and consequently are to be recommended, but hand work gives satisfactory results,

and the selection of the method to be employed must be largely determined by the available supply of efficient labor.

"If it is intended to tar an old surface, it is advisable to take advantage of the early months of the year to scrape or brush

FIG. 105. Garden Watering Pot Used for Distribution of Bituminous Material.

the road during wet weather as a preparation for subsequent tarring, and especially to keep the road free from caked mud.

"If the crust of a road is thin at the sides, but adequate in the center, the sides should be strengthened and consolidated before application of tar to the surface.

"In resurfacing any road the surface of which is afterward to be tarred, stone chippings, and not fine material, should be used for binding.

"The road whilst being tarred should be closed to traffic over half its width, or, where practicable, over its whole width.

"The road should be thoroughly brushed and cleaned before application of the tar. Wet brushing should be used some time previous to dry brushing, if there is any caked mud. Any method of brushing may be used which will scour and clean the road thoroughly, the best being horse brushing, followed by hand brushing.

"Tar should be used for surface tarring which complies with either Road Board Specification for Tar No. 1 or Road Board Specification for Tar No. 2, but if the heavier grade of the tar is used, care should be taken to apply it only when the road is dry and well warmed by the sun's rays, otherwise it will not flow freely.

"The tar should be heated to its boiling point at convenient

FIG. 106. Three Types of Pouring Cans.

positions on the works, and should be applied as hot as possible, so that it may flow freely. The desired temperature will be generally found in practice to lie between 220° and 280° Fahrenheit.

"Immediately on application the liquid tar should be brushed so far as necessary to insure regularity in thickness of the coating.

"The quantity of tar required will vary according to the physical conditions of the road, but generally, in the case of a road to be treated with tar for the first time, the quantity should be one gallon to coat from five to seven superficial yards.

"If the road must be opened for traffic before the tar has set hard, grit should be spread on the surface to prevent the

tar from adhering to the wheels of vehicles, but gritting should be delayed as long as possible, and the quantity of gritting material to be spread should be no more than sufficient to prevent the tar from adhering to wheels. Stone chippings, crushed gravel, coarse sand, or other approved material (free from dust) not larger than will pass through a ¼-inch square mesh should be used for gritting, in quantity not exceeding 1 ton for 300 to

FIG. 107. Perfection Pouring Can.

350 superficial yards if grit is used, and 1 ton for 200 or 250 superficial yards if coarse sand is used.

"On heavily trafficked roads it is advisable to apply a second coat to either the whole width or from 9 to 12 feet of the center of the road in quantity of one gallon to coat from 8 to 10 square yards about two to three months after the first application.

"Surface tarring should be renewed annually on all important roads, and as required on roads with light traffic. On such recoatings the quantity of tar to be applied will vary with the extent to which the previous coating of tar has been removed by weather or by traffic.

"Surveyors are recommended to have samples of the tar supplied to them under contracts properly tested by a qualified analytical chemist for

Specific gravity
Freedom from water
Fractionation
Free carbon."

Mechanical Appliances. The appliances used in the distribution of bituminous materials may be classified as gravity distributors and pressure distributors.

Gravity Distributors. In this subdivision will be considered

Courtesy of Dr. Guglielminetti.

Fig. 108. French Hand-drawn Distributor.

pouring cans, hand-drawn distributors, tanks with hose attached, and machines equipped with horizontal distributing apparatus.

Pouring Cans. It is self-evident that with the use of pouring cans alone it is very difficult to secure uniform application of the bituminous material. However, if the application of the material is immediately followed by vigorous brushing with fibre push brooms, very satisfactory surfaces can be obtained. Naturally, however, the use of these methods will result in a high labor cost due to two factors, the high cost of labor, especially in the United States, and the slow progress made. It is unfortunate that more care is not given to the selection of the

type of pouring cans to be used. For example, the usual type employed for garden watering is hardly adaptable for use in the construction of bituminous surfaces. Nevertheless the photograph, see Fig. 105, showing the use of this type of can exemplifies current practice in the distribution of bituminous material adopted in one locality within a few miles of New York City. Various types of cans, which have given more or less

Courtesy of Dr. Guglielminetti.

FIG. 109. French Hand-drawn Distributor.

satisfaction, are shown in Fig. 106. A very satisfactory type is shown in the accompanying photograph, see Fig. 107. It is, of course, apparent that the more even the distribution of the bituminous material, the less will be the amount of brooming required.

Hand-Drawn Gravity Distributors. The self-evident improvement of a hand-drawn gravity distributor over the pouring can is the more uniform distribution of material, the elimination, to a certain extent, of the personal equation, more rapid work, and the practicability of keeping the bituminous material at a

higher and more even temperature. Hand-drawn gravity distributors were introduced in France in 1903, the types being illustrated in the accompanying views, see Fig. 108 and Fig. 109. At about the same time hand-drawn distributors were introduced into the United States by the Warren Brothers Company, see Fig. 110, and have been used by them in the construction of the flush coat on the Bitulithic Pavement for many years. The

Fig. 110. Warren Brothers' Hand-drawn Distributor.

accompanying view, see Fig. 111, shows the "Eldus," which is one of the latest types of hand-drawn distributors on the market in the United States.

Tanks with Hose Attached. In Figs. 112 and 113 are illustrated two types of tanks from which the bituminous material flows by gravity through a hose and nozzle onto the road. Brushing is usually necessary when this type of distributor is employed. A special form of apparatus coming under this head is known as Waithman's Reservoir Broom. This apparatus comprises a kettle in which the material is heated and to which are fitted two lines of flexible hose, each of which is attached to the head of a hand push broom. The tar flows through this flexible hose into the head of the broom, and is thence swept into the road

by the men operating the brooms. One man pulls the tar kettle, two work the brushes behind the kettle and a fourth man supplies the kettle with material.

Machines with Horizontal Distributing Apparatus. Watering carts were first used in the United States for distributing the light oils and tars for suppressing the dust. The ordinary spray attachments on the carts were not very satisfactory for dis-

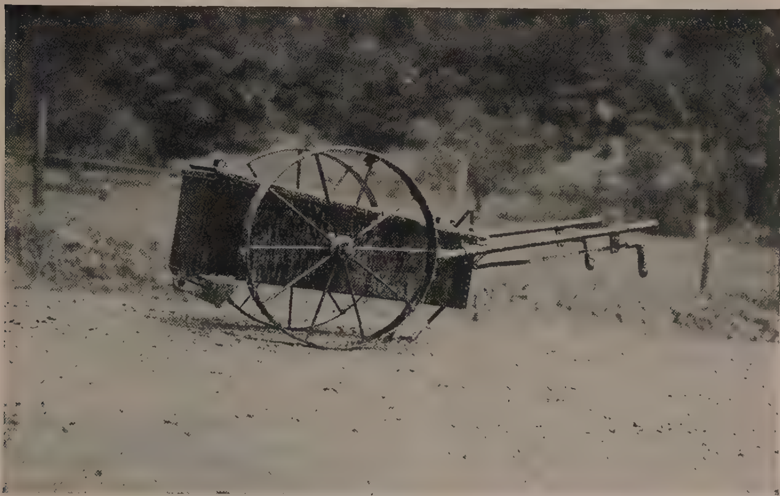


FIG. 111. "Eldus" Hand-drawn Distributor.

tributing this class of material. Attention was then directed to modifying the distributing device, still using the wooden tank wagon. Practically all of the modifications consisted in substituting for the improved type of water sprinklers one or more horizontal pipes pierced with small holes. These pipes were attached to the outlet pipe of the tank and were placed parallel to the back axle at the rear of the tank. The pipes were usually about the same length as the gauge of the rear wheels. The material flowed through these pipes in small vertical streams onto the road surface. In distributing small quantities the road surface would not be entirely covered with the material, but the streams would be separated by the distance between the holes in the distributing pipes. Traffic would work the material

around on the road surface so that in the course of time a fairly satisfactory result might be obtained. The materials were of such a consistency that they could be applied cold. Larger

FIG. 112. Tank with Hose Attachment.

quantities of the material could be distributed by bringing into use at the same time more of the horizontal distributing pipes. This type of apparatus is used to some extent at the present time in the United States.

The general practice in Europe in using machines of this type is to follow the distribution by brushing the material into the road. This is either done by hand brooming or by brooms which are attached directly behind the distributor. The brooms are either of the drag or rotary type. The machines are made to be drawn by hand or by horse. They consist essentially of some form of iron tank having capacity of from 50 to 320 gallons, mounted on wheels, with the distributing attachment at the

FIG. 113. Tank Fitted for Hose Attachment.

rear. This attachment consists of horizontal pipes pierced with holes similar to the arrangement described above. The purpose of the brushing is to distribute the material evenly over the road surface and, in applying small quantities of material by a gravity machine, it is the only way of accomplishing this object. Most of these European machines of the larger sizes are provided with fire boxes for heating the material and with semi-rotary pumps for filling the tanks. The smallest sizes are found to be very advantageous in repair work. The Lassailly, see Fig. 114, and Weeks machines are illustrative of this type of distributor.

As the demand developed for a heavier binder, both for surface treatment and penetration work, machines especially

designed for distributing these materials began to appear. The market at the present time in this country is supplied with so many different types, each one of which is claimed to be "the distributor," that a thorough investigation is essential preceding the acquisition of machines for various classes of work. Among the American distributors of the gravity-flow type may be mentioned the following: the Studebaker improved road oiler;

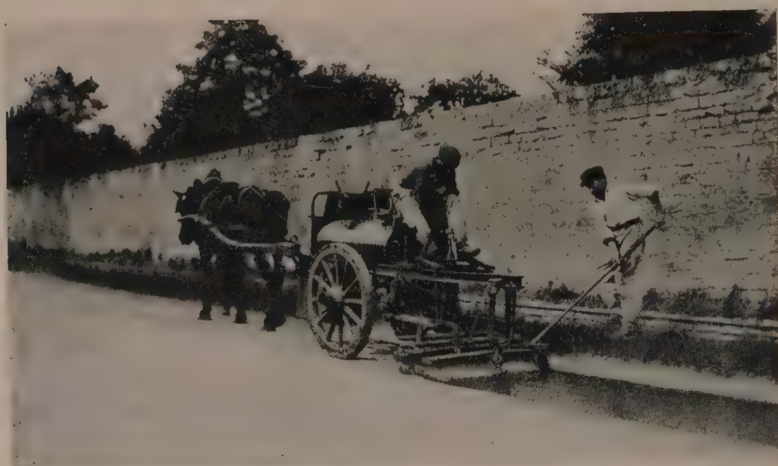


FIG. 114. Lassailly Gravity Distributor.

the Studebaker hot-oil machine; the A. T. C. distributor; the Topping oil sprinkler and distributor; the Good Roads distributor; the Good Roads Improvement Company distributor.

The Studebaker improved road oiler consists of a steel tank wagon of at least 400 gallons capacity, to the back of which are fitted three horizontal distributing pipes, which are parallel and are fed by two large pipes from the tank. Levers are provided for the control of the outflow and are operated by a man on a seat which extends out beyond the pipes. The material flows out of holes bored in the horizontal distributing pipes. This machine is generally drawn by two horses.

The Studebaker hot-oil machine, see Fig. 115, is a 500-gallon steel tank with practically the same type of distributing apparatus as is used on the Studebaker improved road oiler. To obtain

FIG. 115. Studebaker Gravity Distributor.

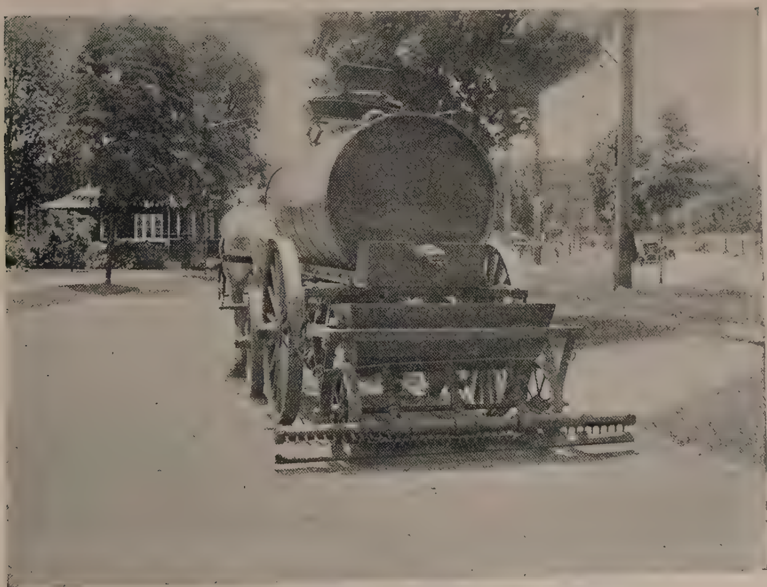


FIG. 116. The A. T. C. Gravity Distributor.

uniform distribution a splash board attachment has been provided. The tank is provided with tubes placed vertically throughout the interior, through which heat is conveyed to the material within the tank. The heat is obtained by means of oil burners placed in a fire box which is the full size of the bottom of the tank.

The A. T. C. distributor, see Fig. 116, is a small trough mounted on two wheels which is intended to be attached to the rear and

Courtesy of the Good Roads Machinery Co.

FIG. 117. Good Roads Gravity Distributor.

underneath the outlet valve of any form of tank wagon. Leading from the trough to a horizontal distributing pipe near the ground are three vertical pipes. The horizontal pipe is fitted with nipples through which the material flows onto a splash board, and thence falls to the road surface in a continuous sheet. This machine requires one man to manipulate the distributor.

The Topping oil sprinkler and distributor is a distributing device designed to be attached to any form of tank wagon. The horizontal distributing pipe is made up of two separate sheet

iron cylinders fed from the cart by two pipes in the form of an inverted V. The material flows into these cylinders, and by means of levers, the outlets of the cylinders are so controlled that a sheet of the material can be spread upon the road. The levers are controlled by a man who sits on a seat over the distributor.

The Good Roads distributor, see Fig. 117, consists of a portable 350-gallon tank, at the rear end of which is fixed the distributing apparatus. The material flows through two pipes into a pipe which extends the full width of the tank, and from this compartment through a V-shaped trough onto the road surface. In this manner the material is applied to the road in a continuous and unbroken sheet. The distributing apparatus is provided with levers and valves for the control of the flow of the material and is operated by one man on a seat over the distributor. This machine may be either drawn by horse or by a steam roller. The tank has a fire box extending underneath it for its full length and is heated by means of a direct fire. The distributing apparatus is also cased in and connected with the fire box so that, if it is desired, heat may be passed around all of the pipes even while the machine is distributing the bituminous material.

The Good Roads Improvement Company distributor is similar to the Topping in that it is designed to be attached to any form of tank wagon. The material flows through two pipes connected with the bottom of the tank wagon to the horizontal distributing pipe. The amount of the material distributed is controlled by the man operating the levers who rides on a seat over the distributor. This same company has also designed a special form of heating apparatus consisting of kerosene oil burners. It is so arranged that it can be attached to any form of steel tank wagon without any riveting being required.

Pressure Distributors. The various types of distributing machines of this class may be grouped in the following subdivisions: hand-drawn distributors; pressure tanks to which are attached hose and spraying devices or horizontal distributing apparatus; and machines equipped with mechanical power pumps between the tank and the distributing apparatus.

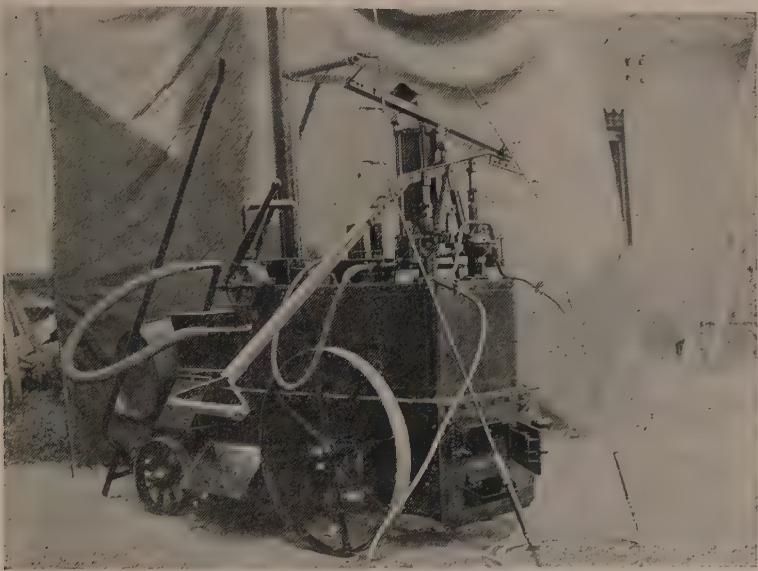
Hand-Drawn Pressure Distributors. Two European machines of this type are shown in Figs. 118 and 119. Essentially these machines consist of a tank for holding the material, the tanks being heated by direct fire, a semi-rotary pump with a length of suction hose attached to the tank for the purpose of filling the latter, and another pump attached to the tank by which it is possible to generate a pressure between the pump

FIG. 118. English Hand-drawn Pressure Distributor.

and the nozzle. The material is pumped from the tank through a length of flexible hose to the outlet end of which is fixed an iron pipe fitted with one or more nozzles. The nozzle is of such a form that the material is thrown in a fine cone-shaped spray. When the machines are equipped with five or six nozzles they are so arranged that a two-foot width of surface can be covered at a time, the nozzles being fixed to a pipe on two small wheels. When one or two nozzles are used, the distribution is effected by passing them over the road surface, the pipe being held up by the men. Both the pump for filling and for pressure are operated by hand, hence it takes at least two men to operate this type of machine, one to run the pressure pump while the other manipulates the hose.

Pressure Tanks. Steel tank wagons of 600 gallons capacity

equipped with steam coils or other means of heating the material and with appropriate fittings so that pressure may be obtained within the tank have been used to some extent in the United States for distributing tar and tar-asphalt compounds in constructing roads by the penetration method. A flexible hose with a nozzle is attached to the outlet valve of the tank by means of which the material is applied to the road. The tanks are



Courtesy of Herr Adolph Stephan.

FIG. 119. German Hand-drawn Pressure Distributor.

hauled by a steam roller which not only supplies steam for heating the material in the tank, but also furnishes the steam for the pressure. The pressure is obtained by admitting the steam into the tank above the bituminous material, the latter being forced out by the pressure of the steam between the material and the top of the tank. By an arrangement of the piping system, means are provided at the outlet valve of the tank so that the steam can be admitted to either side of the valve. The valve or the hose can be easily and thoroughly cleaned out before the distribution of the bituminous material is commenced by simply allowing hot steam to pass through the same. Several

types of nozzles at the hose end have been tried. One form is the round pipe with the outlet flattened to a slot. This nozzle does not throw as good a spray as a special nozzle cast in such a form that the material is given a twisting motion just before it leaves the nozzle, resulting in a cone-shaped spray. Two men are generally used with this machine besides the man on the roller. One man is at the nozzle end of the hose and the other

FIG. 120. Pillsbury Pressure Distributor.

clasps the hose about midway of its length, and drags it around as the nozzle man distributes the material.

The Pillsbury distributor, see Fig. 120, is attached to a specially designed steel tank wagon capable of containing steam under pressure. The tank wagon is drawn by a steam roller, the boiler of which is connected with the tank wagon, furnishing pressure on the bituminous material in a manner similar to that described for the pressure tank wagons and hose distributors.

One of the most famous pressure machines in Europe is known as the Aitken distributor, see Fig. 121. This machine consists of a tank at the rear end of which is fixed a small cylindrical pressure tank connected with the air and tar pump. The quantity of air and tar admitted to the compression tank can be

Courtesy of Thomas Aitken, Esq.

FIG. 121. Aitken Pressure Distributor.

easily regulated. The material is spread on the road through a horizontal distributing pipe fitted with spraying nipples. Where large areas have been covered by superficial treatments, this machine has given excellent results in England. The tanks are provided with means of heating the bituminous material.

Pressure Distributors Equipped with Mechanical Power Pumps. Several pressure machines of this type have been invented in

FIG. 122. Ward Pressure Distributor.

the United States, the most widely known being the Ward distributor, the Johnston distributor, the H. P. spreader and the Miner distributor. The distributing devices of all of these machines are alike in having horizontal pipes fitted with nozzles. The machines differ somewhat in the way the pressure is obtained and applied.

The Ward distributor, see Fig. 122, employs a gasoline engine and pump which is either attached directly to the tank or placed on a separate carriage. The pump is placed between the tank and the distributing pipes and draws the material from the tank and forces it through the nozzles at a pressure of about 30 to 50 pounds.

The Johnston distributor is separate from the tank wagon and consists of a steam pump mounted, together with the dis-

tributing pipes, upon a truck. For its operation it requires, of course, a steam roller, which furnishes the steam for the pump, the roller drawing the tank wagon and the distributor. The truck to which the pump and distributor are attached has a steering wheel so that the man operating the distributor may guide it independently of the roller or tank wagon. The H. P. spreader is similar in construction and in method of operation to the Johnston distributor.

The Miner distributor, see Fig. 123, consists of a 650-gallon tank wagon on the rear of which is mounted a duplex pump.

FIG. 123. Miner Pressure Distributor.

The tank is heated by steam coils. The pump draws the material from the tank and forces it through a horizontal distributing pipe fitted with nozzles. The pump can also be used to fill the tank. In front of the nozzles is a steam jet which serves to blow the dust from the surface.

The Monarch distributor, see Fig. 124, the United Gas Improvement Company distributor, see Fig. 125, and the French machine of Hedeline and Voisembert, see Fig. 126, are each equipped with a pump run by a sprocket drive. The American machines distribute through a series of nozzles attached to a horizontal pipe, while the French machine distributes in a large fan-shaped sheet from a single nozzle.

Examples and Cost of Construction. The method followed by the Los Angeles County Highway Commission in the constructing of an asphaltic oil surface on a newly constructed macadam road is as follows:

"The wearing course, approximately 2 inches in thickness, is composed of rock from ¾ to 1½ inches in size, which is thoroughly rolled, having the voids filled with ¼ to ¾-inch clean

Courtesy of the Good Roads Machinery Company

Fig. 124. Monarch Pressure Distributor.

screenings. This course is thoroughly rolled and watered, leaving a true well-bonded surface within ½ inch of finished grade. This surface must be finished in such manner that the screenings reach to the top of stone, but do not cover same or form pads or cemented patches over the surface. The success of the road depends largely upon the uniformity of this surface, previous to oiling. Any irregular or cemented patches should be broomed. When the surface has dried to a depth of 1 inch or more, and during the warm part of the day, heavy asphaltic oil is applied at a temperature of 212 degrees Fahrenheit, being atomized or sprayed on the surface under pressure of from 30 to 50 pounds per square inch. This coat of oil is applied at the rate of 1

Courtesy of the United Gas Improvement Company.

FIG. 125. United Gas Improvement Company Pressure Distributor.

gallon per square yard. Clean rock screenings are then uniformly spread over the surface to bond the wearing course and form a true surface barely covering the oil, with no excess patches. The surface is then thoroughly rolled and again oiled at a rate of approximately ⅜ gallon per square yard, and uniformly covered with a light coating of rock screenings under ¼ inch in size, in sufficient quantity to take up all oil, usually requiring

FIG. 126. Hedeline and Voisembert Pressure Distributor.

two or more light applications of the screenings, after which it is rolled until it becomes hard and smooth, and is immediately thrown open to traffic. On all new work advertised, the contractor is required to place a final sealing coat on the wearing surface after the road has been open to public travel for two months. This permits the surface of road to be toughened by travel. The coating consists of asphaltic oil, atomized under heavy pressure, applied at a rate of ⅛ to ¼ gallon per square yard, as the surface requires, uniformly covered with very fine rock screenings and coarse sand, and rolled. As a result of the past season's work, the specifications now require that all oil shall be applied with a machine which will apply the oil under pressure of not less than 30 pounds per square inch, and which is capable of perfectly coating every particle of the road with as

small a quantity as 1/8 of a gallon per square yard. It is required that the oil distributor shall have a width of not less than 8 feet. A temperature of 212 degrees Fahrenheit is required in applying."

In Massachusetts the State Highway Commission has maintained many miles of the State Roads by constructing a bituminous surface as described by A. W. Dean, M. Am. Soc. C. E., as follows:* "If the road is subjected to light motor vehicle traffic and light team traffic only, with the motor vehicles predominating, experience has shown that an asphaltic oil of such viscosity that it requires heating to at least 250 degrees Fahrenheit before application, forms a bituminous surface that withstands the traffic and thoroughly preserves the road for a period of time depending partially upon the quality of the material and workmanship and partially upon the quantity of traffic. In the preparation of the broken stone surface, extreme care should be used to sweep and remove every particle of dust and dirt so that the stones will be absolutely bare. Many failures of bituminous surfaces can be traced directly to improper preparation of the broken stone surface, the heavy oils being distributed on dusty and dirty sections, consequently peeling up through lack of adhesion. In order to get the best adhesion of asphaltic oils, it appears that the stone surface should also be a little moist rather than extremely dry. Where the traffic is confined exclusively to motor vehicles, sand appears to be as effective for covering as any material, but if there is some steel-tired horse-drawn traffic, a coarse material like pea-stone or fine gravel is necessary. The average cost during the year 1910 was a little under 8 cents per square yard, and during 1911, a little over that price, with labor costing from $1.75 to $2.00 for an 8-hour day, and asphaltic oil costing 6 cents per gallon delivered in tank cars. The details of the cost on an average road were as follows per square yard of surface:

* See Trans. Am. Soc. C. E., Vol. LXXV, p. 549-550.

Cleaning and sweeping	$0.0056
Patching old surface	.0016
Cost of oil	.0319
Heating oil	.0031
Delivering oil	.0038
Distributing oil	.0029
Furnishing sand beside road	.0165
Spreading sand	.0073
Watering	.0012
Rolling	.0002
Supervision	.0025
Total	$0.0766

This road was treated with 0.5 gallon of heavy asphaltic oil in two applications of 0.25 gallon each. The average haul was two miles for the oil and two and one-half miles for the sand. No allowance is made in the detailed statement just given for rental or depreciation of machinery, or for profits to contractor, the work being done by labor force account."

A method which has been tried with success in Newton, Mass., is described by Charles W. Ross, Assoc. Am. Soc. C. E., as follows: * "A quantity of sand was heated to a temperature of about 200 degrees Fahrenheit, dumped in a pile, and leveled. The asphalt was poured over the hot sand, in a proportion of 1 gallon to each cubic foot of sand, and then the whole mass was turned with shovels or mixed in a concrete mixer (the latter being preferable on account of cost). This work was done at the pit. The mixture was teamed to the work and spread on the roadway to a depth of less than ¼ inch, being raked even with 14-tooth wooden rakes. Rolling was not considered necessary, and the street was kept open for traffic at all times. The cost of this treatment was about 3 cents per square yard. It has the advantage of leveling and building up the surface of the road, each new application providing a new wearing surface."

W. D. Uhler, M. Am. Soc. C. E., states that † "The cost of surface applications on the State roads of Maryland during 1911

* See Trans. Am. Soc. C. E., Vol. LXXIII, p. 47.
† See Trans. Am. Soc. C. E., Vol. LXXV, p. 551–553.

varied from 1.8 to 8.93 cents per square yard, or from $148 to $734 per mile; the bituminous material from 3.75 cents to 9.1 cents per gallon, f. o. b. point of delivery; grit for top dressing from 0.33 to 3.5 cents per square yard in place, depending on character and location of same. With the exception of 16 miles which were applied under pressure, all bituminous material was applied with gravity oilers. While varying conditions will affect the figures slightly, a fair average in detail of the costs given in the table would be as follows:

Sweeping	.0015	cent	per	square	yard
Pitch (delivered)	.0300	"	"	"	"
Applying pitch	.0045	"	"	"	"
Grit (delivered)	.0030	"	"	"	"
Applying grit	.0010	"	"	"	"
Total	.0400	"	"	"	"

The following table gives typical cost data covering bituminous surfaces constructed by the Metropolitan Park Commission of Boston, 1910.

COST PER SQUARE YARD IN DETAIL OF BITUMINOUS SURFACES

Labor	Broken Stone	Sand	Kind of Material	Gallons per Sq. Yd.	Material	Total Cost
$.031	$.031		Tarvia	.60	$.053	$.115
.004	.016		Asphaltic Oil	.61	.040	.060
.037	.016		Tarvia	.64	.055	.108
.004		$.016	Liquid Asphalt	.327	.027	.047
.011		.025	Liquid Asphalt	.40	.032	.068
.025	.020		Tarvia	.22	.018	.063
.012		.020	Liquid Asphalt	.49	.040	.072
.024	.026		Tarite-Asphalt	.60	.048	.098
.013	.012		Tarite-Asphalt	.43	.039	.064
.04	.009		Tarvia	.60	.045	.094

Maintenance

The life of a bituminous surface and its economical use depend primarily upon traffic conditions, the method of construction, and the nature of the bituminous material used. With the heavier grades of bituminous materials adaptable for

this work, if the road is subjected to a normal traffic for which the method and material are economical and suitable, retreatment is necessary every one or two years. Under traffic conditions calling for some other type of construction, it may be necessary to retreat the road twice each year, as is done in the case of the Avenue du Bois de Boulogne in Paris. Retreatments can generally be accomplished by using a smaller amount of bituminous material, usually about half the amount used in the first treatment. The same care should be taken in prepar-

FIG. 127. Repairing Surface Preparatory to Superficial Tarring, Avenue du Bois de Boulogne, Paris.

ing the road surface as is done in the original treatment. Fig. 127 shows the care exercised in filling all holes in the bituminous surface of a Parisian boulevard preparatory to retreatment. Continuous repairing methods are, of course, productive of the most satisfactory results, provided the methods and material adopted are suitable. As it is difficult to barricade a road after small repairs have been made, a type of material should be used which will prevent displacement of the road metal employed in patching.

Philip P. Sharples, Chief Chemist, Barrett Manufacturing Company, emphasizes one important phase of the maintenance

of bituminous surfaces in the following quotation.* "In choosing the bituminous material for a surface which will have to be renewed often, care must be taken to select a material which will allow the application of repeated layers. The speaker has seen a number of roads where the material gave good results on the first treatment, but where further treatments added from year to year have produced a rolling and easily moved surface, due to the formation of a thick, plastic blanket. Where a road is to receive successive applications, it would seem to be important to choose a material which will set up or dry out sufficiently to give good results even after a good many treatments."

Characteristics

The status of bituminous surfaces in 1910 in Europe was outlined satisfactorily in a portion of one of the conclusions adopted at the Second International Road Congress held in Brussels in 1910. The portion referred to reads as follows: "The Congress believes that superficial tarring may be considered as definitely accepted in practice and that the advantages to be derived from spreading fine sand or suitable stony material after tarring and rolling the same is not at present proved and should be the subject of comparative tests; that in the future applications of these methods the attention of road builders should be drawn to the comparison of results obtained by the laying of bituminous substances, hot or cold, by machine or by hand, both from the point of view of cost and from the point of view of the efficiency of the operation; that it is desirable, in comparing results, to take into account the quality of the materials composing the metalling, the intensity of traffic and tonnage as well as the climate; that it would be desirable to establish a comparison between the advantages of tarring, this word being taken in its broadest sense, under different conditions, that is, whether the operations are to be frequently repeated, small amounts

* See Trans. Am. Soc. C. E., Vol. LXXV, p. 560.

being applied each time, or whether large quantities are to be applied at longer intervals, and furthermore whether, or not, a bituminous substance has been incorporated in the metalling."

Advantages. It is apparent that a bituminous surface on a macadam or gravel road, constructed with the proper kind of bituminous materials, renders a road more durable and enables the crown to be reduced, thus distributing traffic and avoiding concentrated wear. The ease of traction and the character of the foothold will, of course, depend upon the kind and amount of the bituminous material used and the grade of the road. Certain materials, while offering a good foothold, may increase the traction, while the use of other types of materials may result in a surface similar to that of a sheet asphalt pavement. Properly constructed bituminous surfaces can be easily cleaned. It is a fact, however, that many types of bituminous surfaces, which give results satisfactory to those who have constructed them, are cleaned with difficulty. It is evident that reference is here made to some kinds of bituminous surfaces constructed with certain asphaltic oils. When asphaltic materials are used the noise caused by horse-drawn vehicles is comparable to the noise characteristic of wood block pavements subjected to the same kind of traffic, while bituminous surfaces constructed with a thin coat of tar give forth much more noise, in some cases comparable to that emanating from the impact of horse-drawn vehicle traffic on sheet asphalt pavements. If properly constructed, bituminous surfaces are practically impervious, yield no dust in appreciable amount by abrasion, and are generally comfortable to use. It is self-evident that the various types of bituminous surfaces are adaptable to many conditions, hence complete preliminary investigations are requisite before the kind of material and the details of the method of construction are adopted.

Disadvantages. Among the disadvantages may be cited a reduction in maximum grade over the ordinary water-bound macadam road due to slipperiness of certain surfaces; formation of greasy mud from the use of asphaltic oils with the consequent damage to the clothing of pedestrians and to household furnish-

ings due to tracking; liability of failure. Opinions relative to the danger to fish life, irritation of eyes by tarred dust, and destruction of vegetation resulting from superficial tarring are also presented below.

Tars. The disadvantages which have been advanced relative to certain bituminous surfaces constructed with tars will first be considered.

Slipperiness. Considerable objection has been raised in England to superficially tar coated roads due to alleged slipperiness. Although toe and heel calks were used, there has been much slipping, with numerous bad accidents. On the other hand, it has been claimed that, due to the use of sharp calks on the shoes of horses, the chisel-like edges penetrate the tarred surface, thus allowing infiltration of water, with the result that the tar is lifted up and causes a greasy film to appear on the roadway. Without doubt much slipperiness is due to a smooth coat of tar, the ideal mosaic surface of tar and stones not being in evidence. Heavy traffic and late tarring contribute to greasiness of a road with consequent slipperiness, since tar lately applied under heavy traffic works up into an emulsion more readily than tar which was applied at the beginning of the season and has set hard by winter.

Danger to Fish Life. It is evident, if proper precautions are taken during the treatment of a road with tar and if refined tar of proper quality is employed, that very little danger of pollution of fish streams exists. It has been admirably shown by W. J. A. Butterfield, Assoc. Inst. C. E., however, that if crude tars, having considerable ammoniacal liquor, are used in a manner which will permit of portions of the tar being washed into the stream, it will result in killing certain kinds of fish, trout being especially susceptible. H. P. Maybury, M. Inst. C. E., contends that refined tar will not cause damage to fish life while crude water gas tars may. In order to protect the County of Kent, Mr. Maybury has constructed intercepting chambers through which the road water is filtered before reaching fish streams.

Injury to Vegetation. The opinion has been expressed by

John R. Rablin, M. Am. Soc. C. E., Linn White and Charles W. Ross, Assoc. Am. Soc. C. E., that superficial tarring does not injure vegetation, and such leading English engineers as H. P. Maybury, M. Inst. C. E., and R. J. Thomas, M. Inst. C. E., likewise do not admit deleterious results except from the possible prevention of the percolation of water through the road surface to the trees, since the use of tar makes the surface impervious. An exhaustive inquiry in Germany in 1911, undertaken by "Der Strassenbau," failed to elicit any definite information to the effect that tarred dust was injurious to plant life. Although certain horticulturists in France have claimed that tarred dust injures vegetation, proof of this assertion has not as yet been presented. According to Monsieur Griffon, a Paris expert horticulturist, there is no injurious effect on plants due to tar vapors or fumes during construction.

Irritation of Eyes by Tarred Dust. According to Dr. Guglielminetti there have been no complaints in France relative to the harmful effect of tarred dust on the eyes of pedestrians. The conclusions of Truck and Fleig of Germany are to the effect that tarred dust, rising from newly superficially coated roads, produces conjunctivitis of a very marked character. However, they also conclude that the diminution of ordinary dust more than counteracts the injurious effects of tarred dust.

Asphaltic Oils. Among the disadvantages of using asphaltic oil of certain types may be mentioned the ruining of carriage varnish, clothing, and floor coverings by the black greasy mud which is characteristic of roads treated with many asphaltic oils.

Failures of Bituminous Surfaces. The causes of failure of bituminous surfaces are numerous. They may be considered from the standpoint of the condition and character of the original surface, the material used, the method of construction, and local conditions.

Condition of Surface. The failure of bituminous surfaces from the standpoint of the character of the original surface is many times due to failure on the part of those in charge to place the surface in satisfactory condition before the application of the bituminous material. Many cases are noted where bituminous

materials are applied over a surface in which are found many pot holes and ruts, or which is dirty, due either to accumulated dust and dirt or to the original method of construction. With certain kinds of materials a damp condition of the surface has resulted in failure. See Fig. 128.

Bituminous Material. From the standpoint of the physical and chemical properties of the material, many instances may be

FIG. 128. Failure of Bituminous Surface Due to Dampness Prior to Treatment.

cited in which failure is due to materials not having the proper characteristics for the conditions under which they are employed. As an example might be cited the case of a prominent thoroughfare in one of our large cities which is subjected to motor-bus traffic and a large amount of motor-car and horse-drawn vehicle traffic. This road is constructed of gravel upon which has been applied an asphaltic oil and gravel top dressing. The surface at the present time in many sections is full of ruts caused by the traffic pushing the material from side to side. Again the large percentage of volatile constituents contained in certain

Fig. 129. Failure of Bituminous Surface Due to Excess of Bituminous Material.

Fig. 130. Calk Holes in a Bituminous Mat Surface.

asphaltic oils has rendered surfaces constructed with them unsatisfactory because of the long period required for these surfaces to "set up," so that the bituminous material will not track or the carpet thus formed will not creep and form waves and humps. In certain cases the use of light oils on tar or asphalt surfaces has softened the original bituminous surface to such an extent as to render the road or pavement unsatisfactory for use.

Construction Methods. From the standpoint of construction, failures are due both to the use of too small an amount

FIG. 131. Bituminous Mat Surface Torn Up by Passage of Iron Tires.

of the bituminous material and an excess of material. Fig. 129 shows the effect of using too much material. Improper application, resulting in uneven distribution, is accountable for many failures of bituminous surfaces, while in other cases a lack of sufficient covering of stone chips or material of a similar character has rendered the surface sticky and mushy.

Unsuitability. There are numerous instances where bituminous surfaces have been adopted under conditions which call

for the construction of bituminous concrete pavements or even some type of block pavements. A mat type of construction, which has been employed to a considerable extent, has proved inefficacious in cases where horse-drawn vehicle traffic has been more than a certain amount in combination with a motor-car traffic which in amount was not sufficient to iron out satisfactorily the calk holes caused by the horse-drawn vehicle traffic. Figs. 130 and 131 show, respectively, the effect of the impact of horses' feet on some mat surfaces and the tearing up of the surface by the passage of the iron tires covered with foreign material, causing adhesion to the bituminous surface.

CHAPTER XIII

BITUMINOUS GRAVEL AND BITUMINOUS MACADAM PAVEMENTS

The explanatory definitions with reference to the construction of bituminous pavements by penetration methods given in Chapter X will be repeated in order to avoid a confusion of ideas in treating of the various methods of using bituminous materials.

The most common types of bituminous pavements constructed by penetration methods are covered by the following definitions.

Bituminous gravel pavements are those composed of gravel and bituminous materials incorporated together by penetration methods.

Bituminous macadam pavements are those consisting of broken stone and bituminous materials incorporated together by penetration methods. This definition was adopted at the New Orleans Meeting in 1912 of the Association for Standardizing Paving Specifications.

Development. The penetration method of constructing bituminous pavements has come into popular use in the United States since 1908 in building country roads and residential streets due to its low first cost and the large yardage which can be constructed per day. Under the jurisdiction of the State Highway Departments of Maine, New Hampshire, Massachusetts, New York, New Jersey, Pennsylvania, and Maryland, the superficial yardage of bituminous pavements constructed by penetration methods was 63,000 in 1908, while in 1911 it had increased to 8,802,800.

The fundamental reasons for the adoption of bituminous macadam pavements by many municipal engineers are given as follows in the introduction of the "Report of the Committee on

Macadam Paving Specifications," presented at the 1912 Meeting of the Association for Standardizing Paving Specifications.

"Members of this Committee unanimously agree that water-bound macadam pavement is not a proper permanent pavement to lay, for the following reasons:

"First—Since the introduction of the automobile this pavement will not withstand automobile traffic.

"Second—That bituminous macadam can be laid to withstand this traffic at a cost equal to water-bound macadam when the maintenance is taken into consideration. That a water-bound macadam pavement on residential streets, unless properly sprinkled either with oil or water, is an objectionable pavement on account of dust for the abutting property owners, and unless a great deal of care is taken in sprinkling water, the road is injured to a large extent, and if oil is used it can better be done by original construction using a penetration method."

Bituminous Materials

The bituminous materials used in the construction of bituminous pavements built by penetration methods are: asphalts, heavy asphaltic oils, refined water gas tars, refined coal tars, combinations of refined tars, and combinations of refined tars with certain kinds of asphalts. The mining and manufacture of bituminous materials and the various methods used in determining the physical and chemical properties of bituminous materials have been covered in Chapter X.

The characteristic features of specifications for bituminous materials to be used in the construction of bituminous macadam and bituminous gravel pavements are outlined in the following illustrative examples. Two general methods are in use relative to writing specifications for bituminous materials. In one method all types of a general class of materials are covered by one specification. In the other method a separate set of specifications is drawn for each type.

General Specification. The first method is typified by

the following specifications adopted at the 1912 Meeting of the Association for Standardizing Paving Specifications.

"The bituminous cement may be either asphaltic cement or refined coal tar.

Asphalt Cement. "The asphaltic cement may be prepared in the following manner:

"1. From refined natural asphalt;

"2. From the residue obtained in the careful distillation either with or without oxidation of asphaltic or semi-asphaltic petroleum;

"3. From any uniform combination of the preceding materials, together with a suitable flux, if flux be necessary, such combination being subject to the approval of the engineer.

"Each bidder must state the nature and origin of the bitumen to be used by him; and, further, shall submit samples of the bitumen with his proposal.

"The asphaltic cement shall pass the requirements designated below: Penetration shall be from 100 to 180 at 77 degrees Fahrenheit; the above penetrations are measured in hundredths of a centimeter with a No. 2 needle weighted with 100 grams acting for five seconds.

"When 20 grams of the cement are maintained at a temperature of 325 degrees Fahrenheit for five hours in a tin box 2½ inches in diameter, there must not be a volatilization of more than 3 percent by weight of the bitumen present, nor shall the original penetration be reduced thereby over one-half.

"The bitumen of the asphaltic cement shall yield upon ignition not more than 15 percent of fixed carbon.

"The method of test employed is that recommended by the Committee on Coal Analysis of the American Chemical Society.

"Of the bitumen of the asphaltic cement which is soluble in carbon disulphide 98½ percent shall be soluble in carbon tetrachloride. In this test for carbons the asphaltic cement to be tested should be allowed to stand over night covered with purified carbon tetrachloride. The test to be performed in subdued light.

"At 32 degrees Fahrenheit the bitumen of the cement shall

have a penetration of not less than 8 when tested one minute with the needle weighted to 200 grams.

"The cement shall not flash at a less temperature than 350 degrees Fahrenheit, New York State Closed Oil Tester.

Coal Tar Cement. "The coal tar cement shall be a residue of the distillation of coal tar only, and shall be refined for the special purpose of making pavement.

"No mixture of hard pitch with the lighter oils of coal tar will be permitted.

"Its specific gravity shall be not less than 1.20 nor more than 1.29 at 60 degrees Fahrenheit.

"The melting point, determined by the cube method, shall be not less than 105 degrees Fahrenheit, and not more than 115 degrees Fahrenheit.

"It shall contain not less than 15 percent, nor more than 30 percent of free carbon insoluble in benzol.

"It shall be free from water as determined by distillation and shall show upon ignition not more than ½ percent of inorganic matter.

"No distillate shall be obtained lower than 338 degrees Fahrenheit, and, up to 600 degrees, not less than 5 percent, and not more than 20 percent of distillate shall be obtained. The distillate shall be of a gravity of not less than 1.03 at 60 degrees Fahrenheit. The residue shall have a melting point of not more than 165 degrees Fahrenheit. In making this distillation an 8-ounce glass retort shall be used and the thermometer suspended so that before applying the heat the bulb of the thermometer is one-half inch above the surface of the liquid. The melting point of the pitch shall be determined by suspending a ½-inch cube in a beaker of water 1 inch above the bottom. The temperature shall be raised 9 degrees per minute from 60 degrees Fahrenheit. The temperature recorded the instant the pitch touches the bottom shall be considered the melting point of the pitch. In testing the original material the initial temperature shall be 40 degrees Fahrenheit."

Separate Specifications. As examples of specifications

containing certain clauses drawn to cover in each case a specific type of material, the following are cited:

Asphalt, Type A. An asphalt manufactured by combining a native bitumen with refined asphaltic oil.

(1) The specific gravity of the asphalt at 25 degrees Centigrade shall not be less than 0.965 nor more than 1.000.

(2) It shall be soluble in carbon disulphide to the extent of 99.0 percent.

(3) It shall contain not less than 18 percent nor more than 25 percent of bitumen insoluble in 88 degree Baumé paraffin naphtha.

(4) It shall yield not less than 5 percent nor more than 10 percent of fixed carbon.

(5) When 20 grams of the asphalt are maintained at a constant temperature of 170 degrees Centigrade for five hours in a cylindrical tin dish 2½ inches in diameter by 1 inch high, the loss in weight shall not exceed 3 percent.

(6) When tested for five seconds at 25 degrees Centigrade with a standard No. 2 needle weighted with 100 grams, it shall show a penetration of not more than 200 nor less than 150.

Asphalt, Type B. An asphalt manufactured by fluxing a refined native bitumen.

(1) The specific gravity of the asphalt at 25 degrees Centigrade shall not be less than 1.010 nor more than 1.045.

(2) It shall be soluble in carbon disulphide to the extent of 92.0 percent.

(3) It shall contain not less than 18 percent nor more than 25 percent of bitumen insoluble in 88 degree Baumé paraffin naphtha.

(4) It shall yield not less than 9 percent nor more than 13 percent of fixed carbon.

(5) When 20 grams of the asphalt are maintained at a constant temperature of 170 degrees Centigrade for five hours in a cylindrical tin dish 2½ inches in diameter by 1 inch high, the loss in weight shall not exceed 5 percent.

(6) When tested for five seconds at 25 degrees Centigrade

with a standard No. 2 needle weighted with 100 grams, it shall show a penetration of not more than 200 nor less than 100.

Asphalt, Type C. An asphalt manufactured by refining asphaltic oil.

(1) The specific gravity of the asphalt at 25 degrees Centigrade shall not be less than 0.990 nor more than 1.010.

(2) It shall be soluble in carbon disulphide to the extent of 99.7 percent.

(3) It shall contain not less than 15 percent nor more than 25 percent of bitumen insoluble in 88 degree Baumé paraffin naphtha.

(4) It shall yield not less than 9 percent nor more than 13 percent of fixed carbon.

(5) When 20 grams of the asphalt are maintained at a constant temperature of 170 degrees Centigrade for five hours in a cylindrical tin dish 2½ inches in diameter by 1 inch high, the loss in weight shall not exceed 3 percent.

(6) When tested for five seconds at 25 degrees Centigrade with a standard No. 2 needle weighted with 100 grams, it shall show a penetration of not more than 150 nor less than 100.

Coal Tar Pitch. The pitch advocated for use by the Road Board of England in the construction of "Pitch-grouted macadam," to be hereinafter described, is secured under the following specifications:

"The pitch is obtained by softening the material known as commercial soft pitch, as specified below, by the addition of tar oils, also specified below.

"*Commercial Soft Pitch.* The pitch shall be derived wholly from tar produced in the carbonization of bituminous coal, except that it may contain not more than 10 percent of pitch derived from tar produced in the manufacture of carburetted water gas.

"On distillation the pitch shall yield:

"Below 270 degrees Centigrade not more than 1 percent of distillate.

"Between 270 degrees Centigrade and 315 degrees Centigrade, not less than 2 percent and not more than 5 percent of distillate.

"The free carbon should not exceed 22 percent of the weight of the pitch, but if it be found difficult or unduly expensive to obtain this quality of pitch, a quality containing as much as 28 percent of free carbon may be used with a reduced proportion of sand as filler.

"*Tar Oils.* The tar oils to be used shall be derived wholly from tar produced in the carbonization of bituminous coal, or from such tar mixed with not more than 10 percent of its volume of tar produced in the manufacture of carburetted water gas.

"The specific gravity of the tar oil at 20 degrees Centigrade shall lie between 1.065 and 1.075.

"The tar oils after standing for half-an-hour at 20 degrees Centigrade shall remain clear and free from solid matter (crystals of naphthalene, etc.).

"The tar oils shall be commercially free from light oils and water, *i.e.*, on distillation shall yield not more than 1 percent of distillate below 140 degrees Centigrade.

"The amount of distillate between 140 degrees Centigrade and 270 degrees Centigrade shall lie between 30 percent and 50 percent.

"The proportions by weight in which the pitch and tar oils are to be mixed shall be as follows:

"Pitch 88 percent to 90 percent.

"Tar oils 10 percent to 12 percent."

Construction

Subgrade. The subgrade for bituminous macadam and bituminous gravel pavements should be prepared in accordance with principles outlined in Chapter IX on Broken Stone Roads. Proper drainage should be provided as explained in Chapter V on Drainage.

Bituminous Macadam Pavements. As it is usually desired to keep the bituminous material within the upper 2 inches of the road surface and to secure a uniform incorporation of the material as binder, several different methods of construction

have been devised. Due to the lack of uniformity in the density of the surface and the amount of bituminous material applied by the many methods employed, it is obvious that uniform incorporation of the binder with the road metal is difficult to obtain. The average pavement is generally built in two courses, the foundation course being about 4 inches thick after rolling and the top course about 2 inches after rolling. The following methods treat of the use of broken stone as the road metal.

Method A. When the metalling in the upper course consists of a naturally graded aggregate with sufficient smaller sized product to practically fill the voids in the larger, say, crusher-run stone from 1¼ to ½ inch in longest dimensions, it is not necessary to further fill the voids by the application of a finer product before applying the bituminous material. An analysis of the type of crusher-run stone referred to follows:

Passing	¼-inch	screen	trace	
"	½	"	18.9	percent
"	¾	"	43.1	"
"	1	"	34.4	"
"	1¼	"	3.6	"

After the upper course is laid the bituminous material is applied, either before or after the surface is rolled, some favoring the former method because of the greater depth of penetration secured. If the rolling is postponed until after the application of certain bituminous material, the wheels of the roller will have to be wet or oiled to avoid picking up the surface. When the upper course is rolled preceding a second application of the bituminous material, a coat of mineral matter is spread over the surface before rolling. In certain cases this method is also followed where the upper course is not rolled preceding the application of the bituminous material. The necessity of a seal coat or a second application of a bituminous material is determined by the traffic conditions; the surface should be given a seal coat if it is to be subjected to a heavy combined horse-drawn vehicle and motor-car traffic. The material used for the seal coat in some cases has a less penetration and a higher melting point than that used in the first application. Certain

asphalts and combinations of asphalts and refined tars, solid at ordinary temperatures, have been used with success for this purpose.

Specifications. Method A was used in the Borough of Queens, New York City, in 1911. The descriptive specifications covering many of the details of construction follow:

"Laying the Wearing Surface.—Upon the foundation shall be evenly spread, to a depth of 3 inches, loose measurement, a single course of 1½-inch stone. This course shall be dry rolled only until the fragments of stone have keyed together, the surface, while even and conforming to the desired crown, being left open or porous in order to allow penetration of the hot bituminous cement applied in the manner hereinafter specified.

"First Application of Bituminous Material.—The hot bituminous material shall be uniformly distributed over the wearing surface by suitable approved appliances at a rate of 1½ gallons to the square yard. Directly after this application clean, dry, ⅜-inch stone, free from dust, shall be spread over the surface in sufficient quantities to completely fill the surface voids. The road shall at once be thoroughly rolled until solid, more stone chips being applied if necessary. The bituminous material shall be applied only during dry weather, and the stone of the wearing surface must be absolutely dry at the time of such application.

"Seal Coat.—A seal coat of hot bituminous material shall be uniformly distributed over the surface in the manner above described at the rate of ¾ gallon to the square yard. Clean, dry, ⅜-inch stone chips shall then be spread over this seal coat in sufficient quantities to take up all excess bituminous cement and form a smooth, well-bonded surface when rolled. The surface shall be rolled to the satisfaction of the engineer or inspector."

Method B. In case the metalling of the upper course is a uniform product of about 1 or 1½ inches in size, it is deposited in a layer of the required thickness on the foundation course and lightly rolled. The bituminous material is then applied in an amount from 1½ to 2 gallons per square yard and screened

stone chips, about ⅜ inch in size, are spread on the surface and thoroughly rolled. The surface is next broomed with stiff brooms, removing all excess chips, and another coat of bituminous material, from ½ to 1 gallon per square yard, is applied, covered with a layer of stone chips and rolled. This method is also used with metal of the upper course varying from 1½ to 2½ inches, in which case ¾-inch stone is used in place of ⅜-inch chips.

Modifications of this method have been used to a considerable extent by the Massachusetts Highway Commission. The details of the methods have been described as follows by A. W. Dean, M. Am. Soc. C. E.*

"After the subgrade has been properly prepared, broken stone varying in size from 1¼ to 2½ inches is spread to a uniform thickness varying somewhat with the nature of the anticipated traffic, and dependent also upon the quality of the subgrade. If the subgrade is of excellent gravel, a thinner layer may be used in the bottom course than would be used if the subgrade is of poorer material. The most common thickness of this first course is 3 inches after rolling. This course is thoroughly rolled, the voids being entirely filled with stone dust or other suitable material. After this course has been thoroughly compacted, any dust or dirt that may be left on top is cleaned off, and asphaltic oil applied, using for this application ⅝ gallon to the square yard of 90 percent asphalt oil, the application being made while the oil is at a suitable temperature, varying according to the viscosity of the material from 175 degrees to 225 degrees Fahrenheit. Immediately after this oil is applied, stone varying from ½ to 1¼ inches in diameter is spread over the oil, the stone having previously been distributed in piles along the side of the road. The thickness of this stone layer should be fairly uniform and should be such that it will roll to about 1½ inches. After a partial rolling of this course, a second application of oil is made at the rate of ⅝ of a gallon to the square yard, and it is then lightly covered with additional stone of the same size, after which a

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* See July, 1912, *Journal, Assoc. of Engineering Societies.*

third application of oil is made at the rate of about ¼ of a gallon to the square yard, this oil being immediately covered with clean ½-inch screenings, thoroughly watered and rolled. The entire quantity of oil used, when the stone to be bound does not exceed 2 inches in thickness after rolling, should never exceed 1½ gallons to the square yard.

"Roads under similar traffic conditions have been constructed in a few instances, using the same method for the foundations and bottom course of stone as described above, but using tar as a binder instead of heavy asphalt oil. Ordinarily where the tar is used for a binder, it is used in one application of approximately 1½ gallons to the square yard on top of the second course of stone. Some expense is saved in the first cost of a road built with tar in that it saves a second handling of the stone in the second course, this second course being spread as in an ordinary water-bound macadam road, and after it has been partially compacted by rolling, refined tar is applied by a pressure distributor, followed by an application of ½-inch screenings, the whole being then thoroughly rolled and compacted. The reason for the difference in method of applying the oil and tar is that oil penetrates upward as well as downward, whereas tar has a tendency to penetrate largely downward. Tar has not been used very extensively by the Commission for the reason that tar appears to disintegrate under atmospheric action much more rapidly than asphalt products; this disintegration may be prevented, however, and the life of the material prolonged by applying annually a thin surface coating of refined tar."

Method C. In some forms of construction the voids in the foundation course are filled to a certain extent with sand or small sized broken stone. After rolling, the excess sand or broken stone is broomed off, and the upper course of metalling spread and lightly rolled. Coarse sand, stone chips, or gravel is then spread and broomed until the voids of the metalling are filled to the surface. The bituminous material is then applied, using from 1 to 1½ gallons per square yard; this coat is covered with a layer of sand, gravel, or screened stone chips, and thoroughly rolled. This method is often used when the material composing

the upper surface is of a large and uniform size. Sometimes a seal coat of from ½ to 1 gallon of bituminous material is used with this method.

Specifications. Method C has been used by the Illinois Highway Commission, quotations from whose specifications follow:

"Three sizes of crushed stone shall be used as follows:

"(a) Broken to a size that will pass over a 1-inch ring and through a 2½-inch ring, which size will hereinafter be referred to as 2½-inch stone.

"(b) Broken to a size that will pass through a 1-inch ring and be retained on a ⅜-inch ring, which size will hereinafter be referred to as chips. Well graded gravel of suitable sizes may be used for chips on approval of the engineer.

"(c) Broken to a size that will pass through a 1-inch ring, graded to dust and including any dust or finely crushed stone that is obtained in screening the chips, which size will hereinafter be referred to as screenings. Gravel of suitable size may be used for screenings on approval of the engineer.

"The first course of stone shall be of 2½-inch broken stone spread to compact under rolling to the thickness shown on the plans. After the first course of stone has been spread, it shall be harrowed with a stiff tooth harrow (having a weight of 10 to 12 pounds on each tooth) until a uniform size of stone is brought to the surface and all fine material which may have been mixed with the 2½-inch stone has been shaken to the bottom of the layer of stone. After the broken stone for the first course has been spread to a uniform thickness, and harrowed, and has a proper cross-section, it is to be rolled until it is compacted to form a firm, smooth surface.

"After the first course of stone has been rolled and completed as specified, the screenings are to be spread, but in no case are screenings to be used until the first course has been thoroughly rolled and compacted. The screenings are to be spread dry with shovels in a quantity which will just cover the first course of stone. After the screenings are spread, they are to be sprinkled with water from a properly constructed sprinkling car and then

rolled. The rolling and watering shall continue until the water flushes to the surface. If, after rolling the screenings, the stone appears at the surface, additional screenings shall be used in such places.

"The second course shall be of 2½-inch stone and shall be spread to compact under rolling to the thickness shown on the plans. After the second course of stone has been spread, it shall be harrowed as hereinbefore described for the first course of stone. After the broken stone for the second course has been spread and harrowed to the required thickness and has a proper cross-section, it is to be rolled until it is compacted to form a firm, smooth surface.

"After the second course of stone has been rolled and completed as specified, the surface voids are to be filled with chips, free from dust, which shall be whipped into the surface from shovels, the quantity being such as will just fill these surface voids. After the chips have been whipped into the surface, it shall be gone over with a stiff brush broom and all chips remaining on the surface of the stone swept into the voids in the surface, and if an excess remains after the voids have been filled, they shall be swept off to the edge of the macadam.

"Upon the surface prepared as above described, there shall be uniformly distributed approximately 1 gallon per square yard of surface of the binder herein specified. The binder shall be applied at a temperature of not less than — degrees Fahrenheit and shall be spread on the surface in a manner which will insure that a uniform amount is applied to all parts of it. Immediately after the first course of binder is spread, the surface is to be rolled, preferably with a tandem roller, weighing not less than 8 tons. The roller must be provided with means to keep the surface of the wheels sprinkled with water. The rolling is to continue until the surface has become hard, smooth, and as closely compacted as possible.

"After the first course of binder has been spread and rolled as above specified, there shall be spread a quantity of chips which will be just sufficient to fill the remaining voids in the surface The chips shall be brushed into the voids with a stiff brush broom.

"After the second course of chips has been spread and brushed into the surface, a second course of the approved binder shall be spread at the rate of ½ to 1 gallon per square yard. The binder shall be spread at a temperature of not less than—degrees Fahrenheit and shall be applied in such a manner as will insure that a thin even coat of the binder covers the entire surface. After the paint coat of the bituminous compound has been spread, the surface shall be dusted lightly with coarse quartz sand, not to exceed 1 cubic yard per 300 square yards of surface, and the surface rolled with a 10-ton roller, the wheels being wet to prevent sticking. After the surface has been rolled, it shall be allowed to stand for one-half day before being opened to traffic."

Method D. Another method used, when the metalling of the top course is of a large and uniform size, is to place a layer of sand, ¾ inch thick, on the bottom course, the voids of which have been filled. The bituminous material is then distributed on this layer, using about 1 gallon per square yard. The upper course of metalling is immediately placed on the mastic and rolled. Continued rolling forces the material of the upper course down and draws the bituminous mastic up into the voids. Another coat of bituminous material of a lower penetration, using about 1¾ gallons to the square yard, is then applied to the surface of the upper course. A layer of ⅜-inch stone, ½ to ¾ inch thick, is spread over this and rolling continued. The work may stop here or may be carried on a step further by brooming off the excess ⅜-inch stone, afterwards applying another coat of bituminous material, ½ gallon per square yard, adding a layer of screened stone chips and rolling the same. This form of construction, when refined coal gas tar is used, is known in this country as the "Modern Pavement." The Gladwell system, as used in England, is essentially the same in principle except that a course of screened stone chips mixed with bituminous material is substituted for the sand layer and its coat of bituminous material. Rocmac is another type of pavement, first used in England and recently introduced into America, which differs from the Gladwell system only in the character of the binder used and the depth of the mineral matter on the foundation course.

Method E. A bituminous macadam pavement called "Pitchmac" by its originator, J. A. Brodie, M. Inst. C. E., City Engineer of Liverpool, has been constructed in England on a foundation of inferior stone which has been flush coated with bituminous material. On this foundation a layer of 2¼-inch stone, varying from 2 to 4½ inches in depth, is built in from one to three courses, a coat of bituminous compound being applied to each course, and the upper surface being completely covered with screened chips. The bituminous compound consists of refined tar, coal tar pitch, creosote oil, rosin, Portland cement, and certain other ingredients.

Specifications. The essentials of Mr. Brodie's method have been incorporated in specifications adopted by the Road Board of England. Excerpts from these specifications have been quoted to some length:—

"The thickness of the surface coating of pitch-grouted macadam when finished and consolidated by rolling should be 2½ inches to 3 inches (except on very light traffic roads, when the thickness may be 2 inches) for single-pitch-grouting, and from 4 inches to 4½ inches for the double-pitch-grouting hereafter described.

"In the case of naturally hard subsoils, not materially softened by infiltration of surface water, the total thickness of the road crust, including foundation, if any, after consolidation by rolling of the new pitch-grouted surface, should not under ordinary circumstances be less than 6 inches, unless the subsoil is so hard as in itself to act as a good foundation, in which case the thickness of the road crust may be reduced to 4 inches. In the case of clay or other yielding subsoils the total thickness should not be less than 11 inches.

"The finished surface should have a cross-fall of about 1 in 32.

"If the crust is not sufficiently thick at the crown to enable this cross-fall to be obtained with a new coating of the thickness above mentioned, then the old surface should be left intact and unscarified, and the thickness of the new pitch-grouted coating increased as far as may be necessary.

"If the crust is of sufficient thickness for the purpose, the regulation of the cross-fall should be carried out by scarifying the surface and removing material from the crown to the sides previous to the application of the new coating. Material loosened by scarifying should be screened and all material finer than half-inch should be thrown aside.

"The aggregate of broken stone to form the new surface of pitch-grouted macadam should contain broken stone of approved quality of which at least 60 percent must be broken to the size of 2½ inches, and 35 percent to sizes graded from 2½ inches to 1¼ inches. In addition to this 5 percent of chippings of the same stone, varying from ¾ inch down to ⅜ inch, should be used for closing after the grouting with melted pitch.

"It is important that the pitch should not be poured if the surface of the stone is wet. The stone may be protected by tarpaulins, or, if wet, may be dried in situ by portable blowers or other means.

"The quantity of pitch required to grout a single coating is approximately for a consolidated thickness of 2 inches 1¼ gallons per square yard, for 2½ inches 1½ gallons per square yard, and for 3 inches 2 gallons per square yard, but these quantities may vary with different materials, and care must always be taken to fill the voids adequately.

"The aggregate after having been spread and levelled must be rolled down dry until the surface is formed, but without the addition of any small material.

"The pitch, after being carefully melted, must be raised to a temperature of 300 degrees Fahrenheit. Clean sharp sand must be heated on sand heaters to a temperature of 400 degrees Fahrenheit. A dandy, or portable mixing vessel, is then to be filled with equal parts, by measurement, of the heated pitch and the hot sand, and the mixture, hereafter called the matrix, is to be kept well stirred while it is being emptied from the dandy or portable mixing vessel into pouring cans of from 2 to 3 gallons capacity which are used for pouring the matrix on to the roadway. Not only during the process of mixing but afterwards right up to the time of actual pouring, the matrix

must be kept well stirred. The matrix prepared with pitch in the quantities specified should be sufficient to fill the voids of the aggregate.

"The final rolling should be commenced immediately after pouring the pitch matrix, and carried on rapidly before the matrix has time to set. The 5 percent of graded chippings should be spread over the grouted surface in part previously to and the remainder during the process of rolling. The traffic may be allowed on to the finished surface as soon as the surface has cooled to the normal temperature.

"When the traffic is so heavy that a consolidated thickness of from 4 inches to 4½ inches of pitch-grouted macadam is required, it is desirable, in order to obtain the best and most economical results, to divide the coating into two layers, the bottom layer to be the thicker one and to consist of large stones, the two layers being rolled down and grouted separately. Any local stone which can be procured cheaply may, if suitable in quality for foundation work, be used for the bottom layer graded from 3-inch gauge down to 2-inch gauge. No chippings are required for finishing the rolling of the bottom layer. The aggregate for the upper layer should consist of hard road stone of approved wearing quality, broken to 1½-inch gauge, and 5 percent of chippings of the same stone used for the upper layer, graded from ½ inch down to ¼ inch, should be added before and during the process of rolling, and rolled down so as to form the finished surface of the road.

"In pouring the pitch on the bottom layer the surface of the pitch should not be brought to the surface of the stone, but should lie about ½ inch below such surface, with the object of providing a key for the upper layer.

"The quantity of pitch required for double pitch-grouting is approximately for a consolidated thickness of 4 inches 3¼ gallons per square yard, and for 4½ inches 3½ gallons per square yard, but these quantities may vary with different materials, and care must always be taken to fill the voids in the surface coating adequately."

Details of Construction. Reference is here made to the

recommendations pertaining to the construction of bituminous macadam and bituminous concrete pavements contained in the 1912 Report of the Special Committee on "Bituminous Materials for Road Construction" of the American Society of Civil Engineers.

"Crown.—The investigations and observations of the Committee to date have convinced it that the crown generally used in the construction of macadam roads is excessive when bituminous materials are used, and that a crown of even ½ inch to the foot should be avoided when a lesser crown can be secured without detriment to the surface drainage.

"Subgrades and Foundations.—Your Committee believes that the use of any form of a bituminous surface does not preclude the necessity for the construction of a well-drained, thoroughly compacted, and adequate subgrade. In fact, such improvement of the road surface frequently attracts heavier traffic, and thus increases the stresses in the subgrade.

"Your Committee recommends that trap rock in sizes greater than that passing a 2-inch screen should be used with caution in the construction of the upper course, unless the voids of the same are properly reduced, because of the liability of the individual stones to rock under traffic."

Usually better work will be accomplished if the work is done on pleasant days in warm weather. Extreme care should be taken in heating the bituminous material to keep it at the temperature at which it is specified to be used. An increase in temperature may damage the material while, if it is allowed to cool, the amount of penetration will be affected. The bituminous material may be distributed in the same manner as described in Chapter XII. Since the success and economy of the penetration method depend in part upon a uniform distribution of material, a very careful study should be made of the different distributors manufactured, as to the character of the flow and the limitations of the machine, before one is selected for use. In many cases for the seal coat a material is used having a lower penetration and higher melting point than the bituminous material used for the first application. The

distributor which proves satisfactory for the application of the lighter material may not be capable of distributing the heavier material, in which case it is advisable to use a hand-drawn gravity distributor. If a broken stone product is used for the top dressing, the fine dust should be removed either at the crushing plant or by hand screening. The more uniform finish thus secured is fully worth the cost of screening.

Reconstruction. In the reconstruction of old macadam surfaces as a bituminous macadam pavement, the surface is scarified to the desired depth, sufficient new stone is added to bring the surface to the required grade and shape, after which the bituminous material is used in one of the ways previously described.

Bituminous Gravel Pavements. The use of gravel in the construction of bituminous pavements by penetration methods has been usually limited to those localities where the cost of broken stone is in excess of the cost of gravel. It is self-evident that it is impracticable to secure the same keying effect with gravel as can generally be obtained with broken stone. In 1911 under the direction of P. E. Green, M. Am. Soc. C. E., a bituminous gravel pavement was built in Longview, Texas. The method of construction and the conclusions relative thereto, as contained in the following abstracts,* are typical of the practice of many engineers who have used gravel in this class of work.

"Crushed limestone delivered on the streets cost about $3.25 per yard, and even at that price was not the best material, being soft and dusty. A good quality of washed gravel was available at a price delivered on the street of about $2.20 per cubic yard. Gravel is, however, rather unsuitable for use in making a wearing surface which depends on bituminous cement for its bond. The reason for this is that gravel, being generally round and weather-worn, does not 'lock' well together, and the strength of the wearing surface is dependent almost entirely on the bond of the bituminous cement. It was necessary, however, to decide which was to be preferred under the circumstances. The limestone had better locking qualities, but was high in first cost, and the

* See *Municipal Journal*, April 4, 1912.

amount of money available was limited. It was decided therefore to use the gravel and make every effort to lock or bond it by rolling.

"It was specified that the gravel, as spread on the street, should be of a size that would pass a ring of 2-inch diameter and be held on a ring of ½ inch diameter. After a small yardage had been spread under these specifications, it was found that there was no 'lock' at all between the stones, and that when filled with the bituminous cement but little strength was secured. This yardage was taken up and the gravel afterwards used was still further screened so as to eliminate practically all pebbles below ¾ of an inch in size.

"After the surface had been rolled to the satisfaction of the inspector, 1½ gallons per square yard of Texaco asphalt was poured over the pavement, and, immediately behind the asphalt, pea-size gravel was lightly spread over the surface, and the whole rolled again. This was then covered with ½ to ¾ of a gallon per square yard of asphaltic cement, and over this second coat of cement was spread coarse sand, and the whole again rolled.

"On account of the fact that so much care had to be taken with the gravel used, and that it all had to be screened after being received in order to eliminate small pebbles which prevented the locking together of individual stones, it would probably have been cheaper to have purchased crushed limestone in the first place.

"Some conclusions may be drawn as to this method of construction. They are as follows: Gravel can be made to lock and bond only after a great deal of labor and trouble are taken with it. It would probably be economical to pay twice as much for crushed stone as for gravel to get equal results."

Cost Data. The cost of bituminous pavements built by penetration methods varies largely with the amount and kind of bituminous material and road metal used, and the method of construction employed. An average cost, using a total of 2 to 2¾ gallons of bituminous material per square yard, varies from 20 to 35 cents per square yard in excess of the cost of ordinary macadam.

According to A. F. Armstrong, M. Am. Soc. C. E., in 1910

under the New York State Specifications* the average cost of residuum products and filler in place, using one pouring, was 19.9 cents per square yard based on detail data per square yard as follows: 1.45 gallons, cost of same, 15.3 cents; labor, 4 cents; engineering, 0.6 cent; above averages based on average length of 3.31 miles and width of 15 feet. Same material, using two pourings, total average cost per square yard, 23.8 cents; detail cost data per square yard: first pouring, 1.28 gallons; second pouring, 0.37 gallons; cost of material, 17.6 cents; labor, 5.4 cents; engineering, 0.8 cent; above based on average length of 2.45 miles, average width, 15.4 feet. With fluxed Bermudez asphalt in two pourings, total average cost per square yard, 31.9 cents; detail cost data per square yard: first pouring, 1.25 gallons; second pouring, 0.55 gallon; cost of asphalt, 25.6 cents; labor, 5.1 cents; engineering, 1.2 cents; above based on average length of 1.91 miles, average width, 14.4 feet.

The following table† gives construction and maintenance costs as reported by Major W. W. Crosby, M. Am. Soc. C. E.:

TABLE No. 18.

BITUMINOUS WORK ON PARK HEIGHTS AVENUE, BALTIMORE, MD.

Material	Date Used	Construction of Macadam per Sq. Yd.				Maintenance	
		Gal. Used	Cost of Re-s'facing	Cost of Pitching and Chip'ng	Total First Cost	Cost Sq. Yd. 1910	Cost Sq. Yd. 1911
Gulf Co. Asphaltoil A	Aug., Sept., '09	3.97	$0.339	$0.434	$0.773	$0.080	$0.0000
Fairfield	Sept., '09	3.67	.337	.449	.786	.081	.0000
U.G.I. No. 4	Sept., '09	3.12	.339	.344	.683	.081	.0000
Warren Puritan Brand No. 10	Sept., Oct., '09	4.19	.333	.606	.939	.079	.0590
Tarvia X	Oct., '09	5.40	.337	.618	.955	.082	.0000
Am. Tar Co. Tarite	Oct., '09	4.41	.336	.605	.941	.080	.0101
U. G. I. Co.	Oct., '09	3.86	.230	.408	.638	.088	.0362
Gulf Co. Asphaltoil A	Oct., '09	2.95	.229	.405	.634	.082	.2001
U. G. I. Co.	Nov., '09	4.46	.340	.454	.804	.091	.0051
Texas Co.	June, '10	1.25	.397	.264	.661	......	.0044
Headley M. Co.	June, July, '10	1.70	.397	.327	.724	......	.0365
Barber Asph. Co.	July, Aug., '10	1.45	.397	.325	.722	......	.0000
Fairfield Antidust	Oct., '10	0.61	.397	.084	.481	......	.0347
U.G.I. Antidust	Sept., Oct., '10	0.94	.397	.140	.537	......	.1071
Sarco	Oct., '10	1.42	.397	.325	.722	......	.0005
Standard Oil Co.	Oct., '10	1.70	.397	.287	.684	......	.0000
Texaco Special	Oct., Nov., '10	1.46	.369	.414	.783	......	.0031

* See Trans. Am. Soc. C. E., Vol. LXXV, pp. 577–580.

† See Trans. Am. Soc. C. E., Vol. LXXV, pp. 600–601.

F. C. Pillsbury, M. Am. Soc. C. E., Division Engineer, Massachusetts Highway Commission, has given the following descriptions and cost data relative to a standard method of constructing bituminous macadam pavements in his division.*

"One type of road which has been developed under the speaker's observation is a bituminous macadam constructed as follows:

"First: Assuming that the subgrade and surface are properly drained, on the foundation is first placed a layer (4 inches after rolling) of egg-size broken stone, 1¼ to 2½ inches in longest dimension. This layer is thoroughly bound with stone dust or other suitable material, rolled, and flushed with water until it is practically impervious to the bituminous material.

"Second: On this heavy asphaltic oil is evenly distributed, by a pressure distributor, ¾ gallon per square yard.

"Third: On the oil a layer of nut-size broken stone, ½ to 1¼ inches in longest dimension, which will roll to 2 inches thick, is immediately placed and carefully spread with shovels, the carts containing it being driven along the side of the road. The depth of the stone is regulated by wooden cubes placed on the first course, which is sanded at the points where the cubes are placed, in order to prevent them from sticking to the oil. This nut-size stone is then compacted with a steam roller.

"Fourth: On the nut-size stone is distributed under pressure about ⅝ gallon of the same kind of oil as used before, the application being absolutely perfect in distribution, and the penetration reaching well down into the stone.

"Fifth: On the oil is immediately spread fine gravel, gravelly sand, or stone screenings, just sufficient in quantity to fill the surface voids in the nut-size stone, and to take up the thin coating of oil left on the top.

* See Trans. Am. Soc. C. E., Vol. LXXV, pp. 587–589.

Actual Costs of Bituminous Macadam Constructed at North Andover in 1911

Length, 8,107 feet; area, 13,615 square yards; width, 15 feet.

Broken Stone:		
Bottom course:		
Stone, 2,898 tons, at $1.15		$3,332.70
Cost of laying, including unloading, teaming, spreading, rolling, binding, etc.		1,637.70
Total cost for bottom course		$4,970.40
Cost per square yard	$0.3651	
Broken stone dust used to bind bottom course:		
Top course:		
Stone, 1,148 tons, at $1.15		1,320.20
Cost of laying		686.21
Total cost for top course		$2,006.41
Cost per square yard	$0.1473	
Oiling:		
First application, ¾ gallon per square yard:		
Cost of oil per square yard	$0.0438	
" " heating per square yard	0.0225	
" " hauling " " "	0.0025	
" " applying " " "	0.0168	
Total cost per square yard	$0.0856	
Second application, ⅝ gallon per square yard:		
Cost of oil per square yard	$0.0369	
" " heating per square yard	0.0192	
" " hauling " " "	0.0022	
" " applying " " "	0.0168	
Total cost per square yard	$0.0751	
Sand Covering:		
Total cost per square yard	$0.0373	
Cost per square yard for bottom course, broken stone	$0.3651	
" " " " " top " " "	0.1473	
Total	$0.5124	
Cost per square yard for first application of oil	$0.0856	
" " " " " second " " "	0.0751	
Total	$0.1607	
Cost per square yard for sanding	0.0373	
Total	$0.1980	
Total cost per square yard for pavement	0.7104	

Average length of haul for broken stone, 1 mile
" " " " " oil, 1 "
" " " " " sand covering 1 " ; sand not screened.

Broken stone trap rock shipped by rail.
Oil delivered in tank cars.
Cost of labor, 22 cents per hour.
" " teams, 55 " " "

According to P. C. Green, M. Am. Soc. C. E.,* the cost of constructing the bituminous gravel pavement previously described in this chapter was as follows:

Quantities	Grading, including rolling, 1,200 cu. yds.	Curb (wood, 2 x 12″), 1,915 lin. ft.	Foundations (8″ loose), 785 cu. yds.	Top coat, gravel, 404.3 cu. yds.	Asphalt 3,872 sq. yds.
Cost:					
Labor	$587.13	$141.16	$434.01	$629.08	$346.96
Labor, per unit	0.489	0.074	0.112	0.162	0.090
Material	....	95.08	1,393.60	888.58	1,111.25
Material, per unit	......	.050	.360	.230	.287
Total	$587.13	$236.24	$1,827.61	$1,517.66	$1,458.21
Total, per unit	.489	.124	.472	.392	.377

Wages

Foreman	$5.50
Engineer........$5.00 and	3.50
Timekeeper	3.00
Water boy	1.00
Skilled labor	2.50
Labor	1.75
Teams	4.00

Materials

Crushed rock	$1.50 cu. yd.
Gravel and sand	1.87 cu. yd.
Asphalt	20.00 per ton
Lumber	10.00 per M.

Cost per square yard of asphaltic macadam equals $1.40."

Maintenance

The maintenance of many bituminous macadam and bituminous gravel pavements requires covering with sand, gravel, or stone chips spots where either an uneven distribution or an uneven penetration has caused an excess of bituminous material to exude on the surface. See Fig. 132. Places which disintegrate should be cut out with perpendicular sides and refilled with either a mixed aggregate or by building the hole up with suc-

* See *Municipal Journal*, April 4, 1912.

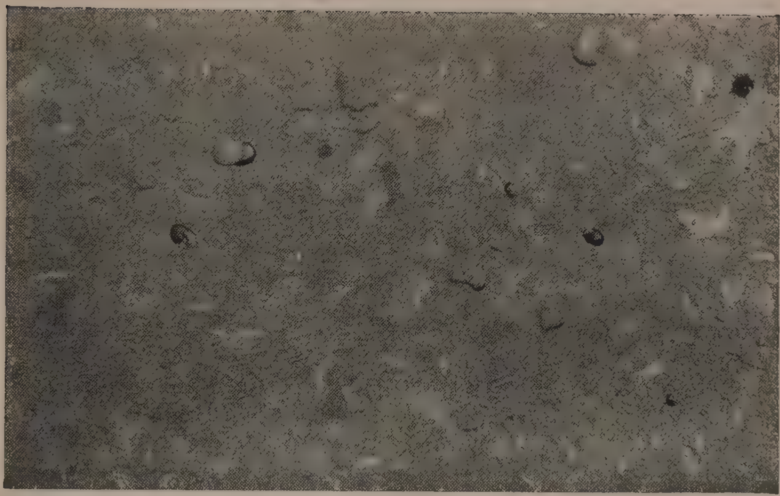

FIG. 132. Bituminous Material Exuding from a Surface.

FIG. 133. Surface of Bituminous Macadam Pavement Prior to Retreatment.

cessive layers of road metal and bituminous material, the former method, however, giving the better results. At varied intervals it is economical to renew the bituminous surface on the pavement by using from ¼ to ¾ gallon of the proper type of bituminous material per square yard. See Figs. 133 and 134. It will be found that the patrol system of maintenance will do much towards prolonging the life of the pavement at a small expense.

Characteristics

Advantages. The advantages incident to the construction of bituminous surfaces on macadam and gravel roads enumerated

Fig. 134. Bituminous Macadam Pavement, Lincoln Park, Chicago, After Application of Asphalt Seal Coat.

in Chapter XII are also characteristic of bituminous macadam and bituminous gravel pavements. It is advisable to emphasize that many bituminous pavements constructed by penetration methods possess the following advantages: suitability for horse-drawn as well as motor-car travel; freedom from dust when in exposed localities; low external and internal wear of road metal; low cost of cleaning, watering, and in many cases of repairs; imperviousness and a certain degree of density of wearing surface;

FIG. 135. Section Showing Uneven Penetration.

FIG. 136. An Illustration of Uneven Distribution of Bituminous Material.

noiselessness and low traction with certain types of bituminous materials; very good from sanitary standpoint.

Disadvantages. Among the disadvantages attendant upon the use of bituminous macadam amd gravel pavements should be noted: increase in cost over bituminous surfaces on macadam and gravel roads; slipperiness when some bituminous binders are used on certain grades; dependence upon climatic conditions in

Fig. 137. An Illustration of Uneven Distribution of Bituminous Material.

order to carry on construction properly; variability in results and lack of uniformity in composition of wearing surface secured due to uneven penetration, see Fig. 135, uneven distribution, see Figs. 136 and 137, and segregation of road metal.

Causes of Failure. The causes of failure of bituminous macadam and bituminous gravel pavements may be considered under the following heads, bituminous material and methods of construction.

Bituminous Material. Unfortunately many are the instances where unsuitable bituminous materials have been employed. In some cases the materials were satisfactory in themselves, but were used improperly. See Fig. 138. Many engineers having charge of bituminous work do not appreciate the fact that different types of bituminous materials have entirely differ-

FIG. 138. Surface of Soft Broken Stone and Asphaltic Oil Subjected to Horse-drawn Vehicle Traffic.

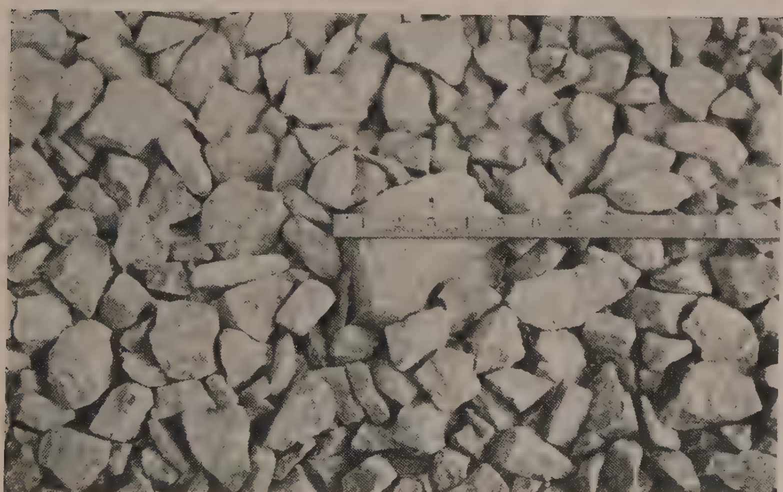

FIG. 139. Surface of Large Broken Stone Prior to Application of Bituminous Material.

ent physical properties and require entirely different treatment in use, although they may have been purchased under one and the same specification covering chemical and physical properties. In some cases entirely unjustifiable combinations of materials are employed. For instance, one case is in mind where an asphalt of excellent characteristics was used for the first applica-

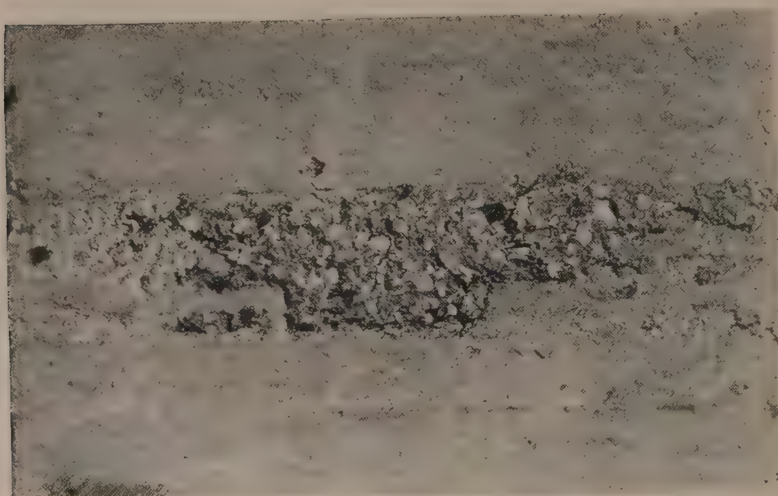

FIG. 140. Soft Seal Coat Torn up Due to Adhesion to Tires.

tion, while for the second application an asphaltic oil having decidedly solvent and fluxing properties was employed. Overheating of the material has likewise proved the cause of many failures as thus the properties of the materials are sometimes changed and in many cases the materials are ruined.

Methods of Construction. Under the heading construction, we find failures due to the uneven distribution of the bituminous material in some cases when horse drawn or power driven distributors are employed. This type of failure, however, is more frequently due to the improper use of hand pouring pots and hand drawn distributors. Many unsatisfactory bituminous macadam pavements result from the use of the wrong sizes of broken stone. One instance will be cited where a hard broken stone ranging from 2 to 3½ inches was used for the

wearing surface. See Fig. 139. After rolling, 1½ gallons of bituminous material were applied and the road finished with a layer of chips. Failures due to the rapid formation of fine cracks caused by the rocking movement of the individual stones under traffic, finally resulting in raveling and general disintegration, are of common occurrence. Segregation of sizes of stone preventing uniform penetration results in weak spots in some cases and "fat" spots in others. In certain cases after a rain the construction has been carried on before the broken stone immediately below the surface has dried out. Many of the causes attributed to the failures of bituminous surfaces may likewise apply to bituminous macadam and bituminous gravel pavements. See Fig. 140.

CHAPTER XIV

BITUMINOUS CONCRETE PAVEMENTS

Development. The first bituminous concrete pavement was probably constructed about 1840 in Nottingham, England, while in the United States the first construction of this type of pavement occurred at Knoxville, Tenn., in 1866. From 1870 to 1875 there were about 70,000 square yards of bituminous concrete pavements laid in Washington, D. C. From 1888 to 1893 many yards of coal tar distillate pavements were laid in Washington because Congress had prohibited the use of sheet asphalt pavements in the District. From 1880 to 1891 several sections of bituminous concrete pavements using coal tar as the bituminous material were laid in Ontario, Canada. Another early bituminous concrete pavement was built in Concord, New Hampshire, and is still in use today. During the closing period of the 19th century attention was directed in England to the details of construction of bituminous concrete pavements for use on highways outside of built up districts. In the United States at the opening of the 20th century Fred J. Warren urged the use of bituminous concrete as a pavement for streets in competition with sheet asphalt, wood block, and brick pavements. Based on experimental work during 1906, 1907, and 1908, Rhode Island in 1909 was the first State to adopt the bituminous concrete pavement as a standard type of construction for use on state highways. Since 1910 there has been a rapidly growing appreciation of the inherent value of many different types of bituminous concrete pavements for use on highways outside built up districts as well as on certain streets of municipalities. Instances of development in this field of construction will be cited later in connection with each of the types of bituminous concrete pavements. Two notable contributions to the literature relative to the historical development of bituminous con-

crete pavements in America are the "History of the Washington Bituminous Concrete Pavements," by Captain Mark Brooke, and the "History of Tar Concrete Pavements in Ontario," by W. A. McLean, M. Can. Soc. C. E.

Materials

Bituminous concrete pavements are those having a wearing surface composed of stone, gravel, sand, shell, or slag or combinations thereof, and bituminous materials incorporated together

Courtesy of Wm. H. Connell.

FIG. 141. Cross-section Bituminous Concrete Pavement. Class 1. B.

by mixing methods. Although in accordance with this definition a sheet asphalt pavement is a bituminous concrete pavement, due to the relative importance of this type of pavement, a separate chapter is devoted to its consideration.

Mineral Aggregates. Bituminous concrete pavements differ principally in the character of the mineral aggregate and the bituminous material of which the wearing surface is composed. Leaving out of consideration sheet asphalt, bituminous concrete pavements may be divided into the following classes and subdivisions based upon the character of the mineral aggregate employed.

Class 1. Mineral aggregates composed of broken stone either alone or in combination with sand.

A. One size crusher-run stone, that is any one product of a crushing plant.

B. Combinations of one size crusher-run stone and fine mineral matter, such as sand or stone screenings, see Fig. 141.

C. Mechanically graded aggregates of broken stone either alone or combined with sand with or without other mineral matter.

Class 2. Mineral aggregates composed of gravel or gravel and sand.

A. Run of the gravel bank.

B. Combinations of screened sizes.

Class 3. Mineral aggregates composed of other materials such as slag, shell, or cinders.

Bituminous Cements. The bituminous materials used in the construction of bituminous concrete pavements are asphalts, heavy asphaltic oils, refined water gas tars, refined coal tars, combinations of tars, combinations of tars and certain kinds of asphalts. The sources, manufacture, and methods used in the determination of the physical and chemical properties of the bituminous materials have been fully considered in Chapter X.

Examples of specifications covering various kinds of bituminous materials which have been used in connection with the construction of the various classes of bituminous concrete pavements under conditions for which they are each adaptable are given to illustrate current practice. These examples also give a general idea of the method of drawing such specifications and the limitations to be specified for the various physical and chemical properties for some of the types of bituminous materials employed. These specifications should not be adopted blindly for reasons heretofore set forth.

The 1913 Report* of the Special Committee on "Bituminous Materials for Road Construction" of the American Society of Civil Engineers contained the following recommendations relative to the advisability of using separate specifications for different types of bituminous materials instead of using one specification covering many types of one class of materials.

* See February, 1913, Proceedings Am. Soc. C. E.

"Your Committee has especially considered during the past year the various methods of writing specifications covering the physical and chemical properties of bituminous materials for use in the construction of bituminous surfaces and bituminous pavements.

"Many of these properties vary to a remarkable degree dependent primarily upon the source of the material and the methods employed in refining. It is recognized that it is often essential to specify narrow limitations of certain properties in order to secure desired chemical and physical characteristics and uniformity in the manufactured material. It is not in many cases practicable to specify the same limitations except for materials obtained from the same or similar sources and prepared in the same manner.

"Therefore it is suggested that for the present at least, whenever comprehensive specifications are to be prepared so as to admit a variety of types of materials, separate specifications as may be necessary be prepared for each type. As an illustration the specification for the bituminous cement to be used in the construction of a bituminous pavement by the mixing method might contain independent specifications covering, within narrow limits, the physical and chemical properties of each of the following bituminous materials: refined water gas tars, refined coal gas tars, mixtures of tars, asphalts containing native bitumen from one or more sources, asphalts obtained by refining petroleum from one or more sources, and asphalts which are solid or semi-solid compounds composed of the bitumens mentioned with petroleums or derivatives thereof."

Class 1. A. During 1911 in the Borough of Queens, New York City, several types of bituminous materials were used in the construction of bituminous concrete pavements of Class 1. A. In one case a refined coal tar was used in the mix for the wearing surface and asphalt cement made from Texas asphaltic oil for the seal coat. The specifications for these materials follow.

Refined Coal Tar. "1. The tar shall have a specific gravity of not less than 1.200 nor greater than 1.250 at 25 degrees Centigrade.

"2. It shall be soluble in cold c. p. carbon disulphide to at least 75 percent and shall contain not over 25 percent nor less than 15 percent free carbon.

"3. Upon ignition it shall show not over 0.5 percent inorganic residue.

"4. When a sample of tar is subjected to the float test, the float shall sink in water maintained at 32 degrees Centigrade in not less than three nor more than four minutes.

"5. When 250 cubic centimeters of the tar are distilled in a 750 cubic centimeter glass retort at a rate not exceeding two drops of distillate per second, the total distillate to 170 degrees Centigrade as registered by a thermometer whose bulb is level with the bottom of the outlet of the body of the retort shall be not more than 1.5 percent by weight of the original material. The total distillate to 270 degrees Centigrade shall not exceed 22 percent, nor be less than 10 percent by weight of the original material.

"6. The tar shall be free from water upon delivery."

Asphalt Cement for Seal Coat. "1. The oil asphalt shall have a specific gravity of not less than 0.990 nor greater than 1.010 at a temperature of 25 degrees Centigrade.

"2. It shall be soluble in carbon disulphide at air temperature to not less than 99.7 percent and shall contain not over 0.15 percent of inorganic matter insoluble.

"3. It shall be soluble in carbon tetrachloride at air temperature to not less than 99.5 percent.

"4. It shall contain not less than 20 percent nor more than 35 percent of the bitumen, insoluble in 86 degree Baumé paraffin naphtha at air temperature.

"5. It shall yield not less than 10 percent nor more than 15 percent of residual coke.

"6. It shall yield not more than 1 percent paraffin scale.

"7. When tested by the cube method it shall show a melting point of not less than 85 degrees Centigrade, nor greater than 95 degrees Centigrade.

"8. When tested for five seconds at 25 degrees Centigrade with a standard No. 2 needle weighted with 100 grams it shall

show a penetration of not more than 6 millimeters nor less than 3 millimeters.

"9. When 20 grams of the material are heated for five hours in a cylindrical tin dish 2½ inches in diameter by 1 inch in height, at a constant temperature of 163 degrees Centigrade, the loss in weight shall not exceed 0.4 percent. The residue thus obtained shall show a penetration of not less than 2.5 millimeters when tested in the manner hereinbefore described, and not less than 1 millimeter when tested at 4 degrees Centigrade."

"Bermudez" Asphalt Cement. The specification for a "Bermudez" asphalt cement used by this method in the Borough of Queens follows:

"1. The fluxed asphalt shall have a specific gravity of not less than 1.010 nor greater than 1.045 at a temperature of 25 degrees Centigrade.

"2. It shall be soluble in carbon disulphide at air temperature to not less than 95 percent nor more than 98 percent, and shall contain not over 2.5 percent inorganic matter insoluble.

"3. It shall contain not less than 18 percent nor more than 25 percent of the bitumen, insoluble in 88 degree Baumé paraffin naphtha.

"4. It shall yield not less than 9 percent nor more than 13 percent of fixed carbon.

"5. When tested for five seconds at 25 degrees Centigrade with a standard No. 2 needle weighted with 100 grams it shall show a penetration of not more than 20 millimeters nor less than 10 millimeters.

"6. When 20 grams of the material are heated for five hours in a cylindrical tin dish 2½ inches in diameter by 1 inch in height, at a constant temperature of 170 degrees Centigrade, the loss in weight shall not exceed 5 percent. The residue thus obtained shall show a penetration of not more than 12 millimeters nor less than 5 millimeters when tested in the manner hereinbefore described."

Class 1. B. The bituminous concrete pavements of this class, laid under the direction of Arthur S. Lewis, Assoc. M. Am.

Soc. C. E., in Lincoln Park, Chicago, were constructed with "Pioneer" asphalt cement. The following specification was employed by Mr. Lewis.

"1. The specific gravity of the asphaltic cement at 77 degrees Fahrenheit shall be greater than 0.98.

"2. The asphaltic cement shall be of a consistency of 5.5 millimeters to 7.5 millimeters penetration at 77 degrees Fahrenheit (No. 2 needle, five seconds, 100 grams). The asphaltic cement shall be of consistency not harder than 3.5 millimeters at 32 degrees Fahrenheit (No. 2 needle, one minute, 200 grams). The asphaltic cement shall be of consistency not softer than 18.0 millimeters penetration at 115 degrees Fahrenheit (No. 2 needle, five seconds, 50 grams).

"3. The melting point of the asphaltic cement shall be between 160 degrees Fahrenheit and 190 degrees Fahrenheit (General Electric method).

"4. The cement shall not flash at less temperature than 400 degrees Fahrenheit, New York State closed oil tester.

"5. When 20 grams of the asphaltic cement are heated for five hours in an oven maintained at a uniform temperature of 325 degrees Fahrenheit there must not be volatilized more than 3 percent of the bitumen present, nor shall the original penetration be reduced thereby over one-half.

"6. The bitumen of the asphaltic cement shall give upon ignition between 8 percent and 14 percent of fixed carbon.

"7. Ninety-eight and a half percent of the material shall be soluble in carbon tetrachloride."

Class 1. C. During 1912 contracts for over one hundred miles of the so-called "Topeka" bituminous concrete pavements were let in the Borough of Queens, New York City. The following asphalt cements, "Bermudez," "California," "Pioneer," and "Texaco," which were used by the Borough in connection with the above work, complied with the blanket specifications given below.

"1. Its specific gravity shall be greater than 0.975 at 77 degrees Fahrenheit.

"2. It must have a penetration between 5 and 10 milli-

meters at 77 degrees Fahrenheit under 100 grams for five seconds, and must be not harder than 1 millimeter penetration at 32 degrees Fahrenheit under 200 grams for 1 minute.

"3. The cement shall be practically free from water, decomposition products, coke or inert free carbon, coal tar or any of its products, or other injurious matters, and the various hydrocarbons composing it shall be present in homogeneous solution, no granular constituents being present.

"4. It must not flash below 350 degrees Fahrenheit when tested in a New York State closed oil tester.

"5. Twenty grams of the cement upon being maintained at a uniform temperature at 325 degrees Fahrenheit for five hours in a cylindrical vessel 2½ inches in diameter shall not lose more than 2 percent in weight, and the penetration of the residue shall not be less than one-half that tested as above described.

"6. It shall be soluble in chemically pure carbon disulphide at air temperature to the extent of at least 95 percent.

"7. Of the bitumen of the asphalt cement which is soluble in carbon disulphide at least 98½ percent shall be soluble in cold carbon tetrachloride.

"8. The bitumen of the cement shall be soluble in 76 degree Baumé petroleum naphtha, at air temperature to the extent of not less than 72 percent.

"9. Upon ignition, the bitumen of the cement shall yield not less than 9 percent nor more than 15 percent of fixed carbon or residual coke.

"10. When tested for ductility at 77 degrees Fahrenheit a briquette of pure bitumen of the asphalt cement having a minimum cross section of 1 centimeter square must elongate to a distance of more than 2 centimeters before breaking. (District of Columbia Method.)"

Bitumen Content in Wearing Surface Mixtures. In specifications and records of work the bitumen content is expressed in one of two ways: first, as the number of gallons per square yard or cubic yard of mineral aggregate; and second, as a certain percentage by weight of the wearing surface mixture. It is apparent that the volumetric amount of bituminous cement

used by the second method materially depends upon the specific gravities of both the mineral aggregate and the bituminous cement. The problem thus presented to the engineer during construction and the chemist in reporting upon an analysis of a surface mixture has been considered by Prévost Hubbard, Assoc. Am. Soc. C. E. A proposed method for avoiding the difficulties mentioned above is briefly described in the following abstracts of Mr. Hubbard's paper.*

"An engineer who superintends the construction of a bituminous road or pavement can, of course, state the volume proportions of the constituents which he uses in a given mix, but if the bituminous material contains considerable mineral matter or organic matter not bitumen, he encounters a serious difficulty in stating the actual proportions of aggregate and bitumen. On the other hand, the chemist who examines a mix can state the weight proportions of aggregate and bitumen, but will often be unable to determine the exact volume proportions in cubic yards and gallons used, owing to considerable variations in the volume of a unit weight of aggregate in different stages of compaction. If the bituminous material originally used contains an unknown amount of mineral matter or organic matter not bitumen, he may also be unable to determine accurately the proportions (either by weight or by volume) of the original constituents which entered into the mix.

"While the subject would seem to be in a more or less chaotic condition in so far as extreme accuracy is concerned, it appears to the author that a much more rational basis of comparison is possible than that ordinarily used. He would, therefore, suggest that in the examination of a prepared bituminous mix the chemist always report the specific gravity of both aggregate and pure extracted bitumen in addition to the usual results. If this suggestion is followed it is believed that an intelligent comparison of different bituminous mixes can be made with little difficulty.

* "The Bitumen Content of Coarse Bituminous Aggregates," Proceedings VI Congress International Association for Testing Materials.

"For example, we may consider a case where wide variations exist in the specific gravity of both aggregate and bituminous material for two different mixes. For a basis of comparison it may be assumed that the two aggregates are found to be practically identical in so far as grading is concerned, and that the percentage by weight and the consistency of the bitumens are the same. According to the ordinary interpretation of results these mixtures would be equivalents. If, however, it is found that the first mix is composed of an aggregate with a specific gravity of 2.50 while the extracted bitumen shows a specific gravity of 1.17, and that the aggregate of the second mix has a specific gravity of 3.50 while the extracted bitumen shows a specific gravity of 0.960, the percentage of each constituent divided by its specific gravity would then give a rational volume proportion, as follows:

Constituents	Per cent. by wt.	Specific Gravity	$\frac{\%\text{ wt.}}{\text{Sp. Gr.}}$ = Rational Proportion	Rational Per cent.
First mix:				
Aggregate	94	2.50	$\frac{94}{2.50} = 37.6$	88.0
Extracted bitumen	$\frac{6}{100}$	1.17	$\frac{6}{1.17} = 5.1$	12.0
Second mix:				
Aggregate	94	3.50	$\frac{94}{3.50} = 26.9$	81.0
Extracted bitumen	$\frac{6}{100}$	0.96	$\frac{6}{0.96} = 6.3$	19.0

"By the determination of what has been termed the rational percent, it is evident that the first mix has a bitumen equivalent of about two-thirds that of the second mix, although the percentages by weight are the same. The rational variation, 7 percent, is certainly sufficient to mean the difference between success and failure for certain bituminous aggregates.

"In conclusion, it may be stated that the rational percent of bitumen will not only serve as an improved means of comparing

different bituminous aggregates which are examined, but may be used to advantage in calculating in advance the proper proportions for a mix if the properties of the constituents of the mix are previously determined."

Construction

Subgrade and Foundation. The subgrade for all types of bituminous concrete pavements should be prepared in accordance with the principles outlined in Chapter IX on Broken Stone Roads. Proper drainage should be provided as explained in Chapter V on Drainage. Satisfactory results have been secured under certain traffic and other local conditions by using a broken stone foundation course varying from 4 to 8 inches in depth for bituminous concrete pavements of Classes 1. A. and 1. B. Heavy commercial traffic will require a cement-concrete foundation course for these classes. Where Class 1. C. can be economically employed usually the cement-concrete foundation will be a prerequisite to satisfactory construction. Large sums have been wasted by laying this type of bituminous concrete pavement on inadequate foundations. Bituminous concrete pavements of Classes 2. B., 2. C. and 3 are usually laid upon foundation courses composed of the same kind of road metal as forms the mineral aggregate. The details of the construction of foundation courses of various types have been explained in Chapters VI, VIII, and IX.

Class 1. A. Pavements of this type have been constructed of one or more courses of bituminous coated metal with and without seal coats of bituminous materials. During the period from 1869 to 1875 many patents were granted by the United States Government covering bituminous concrete of this type.

Patent No. 114,172, granted to F. E. Mathews in 1871, contains the following description of a two-layer bituminous concrete pavement:

"When laid on an ordinary foundation the concrete should be laid in two layers or coats, and should be from 6 to 8 inches thick when finished.

"For the first layer the stone used in making the concrete may be such as would pass through a screen having a 3-inch mesh; about six measures of the stone should be mixed with one measure of the asphalt mixture, and this layer should be about 4 inches thick.

"For the second layer or coat the stone should pass through a screen having a 1½-inch mesh, and be mixed with the asphalt mixture in the proportion of about four parts of the former to one part of the latter, and the second layer should be from 2 to 3 inches thick.

"Fine sand or any suitable fine hard substance may be sprinkled over the last coat just before or after rolling, to give the pavement a smooth compact surface."

Many descriptions of old pavements of this type may be found in technical literature. As an illustration may be cited the following specification used in England in the latter part of the 19th century: "The hot stone, when ready for mixing, is screened into material of three sizes, 1 to 2 inches for the body, ½ to 1 inch for the intermediate coat, and ¼ to ½ inch for the top dressing. The coarsest material is used in a layer 3 to 4 inches thick, the intermediate size forms a coat of about ¾ of an inch, and the top dressing is used in the thinnest layer possible, with a view to filling all interstices. Afterward a dressing of ¼-inch and smaller granite screenings is scattered broadcast, and the traffic at once allowed on the road to work this top dressing into the tarred material. Each of the layers is rolled separately with a 10-ton roller."

The value of the use of seal coats of bituminous materials on bituminous pavements was appreciated by some of the pioneers in the field of highway improvement. In a book entitled "Bituminous Concrete Pavements," published in 1876, N. B. Abbot presents the following pertinent discussion on this detail of construction:

"It is the practice of most of the concrete-pavement men to finish the surface with a top-dressing of dry sand, rolled into the surface; or of hydraulic cement, swept in with a broom. I became early satisfied that some better plan of finishing was

needed. The most compact concretes are more or less porous on the surface; and though these pores are filled with the sand or cement used for top-dressing, neither of these materials being water-proof, in wet weather the water penetrates the pavement, street dirt mingles with the water, and a disintegrating process begins, which soon results in breaks and unevenness of surface. In winter, particularly, the moisture, having penetrated the pavement, freezes and thaws, and decay is hastened. It is just

FIG. 142. Bituminous Concrete Pavement, Class 1. A., Rhode Island State Highway, Built 1906.

as essential that a concrete pavement should be water-proof as that a roof should not leak. My experiments in this direction resulted in what is known as the Abbot Grit Surface, which was patented June 17, 1873. This improvement consists in spreading a hot liquid composition over the surface of the pavement after it is rolled, into which is placed clean, dry grit or sand. This sand is immediately rolled into the surface while the composition is warm, and a tough coating is thereby formed, which not only prevents the pavement from being slippery, but effectually

closes every pore in the surface, and makes it impossible for moisture to penetrate."

Naturally Class 1. A. has been very popular due to its simplicity. Excellent pavements have been constructed by this method where the aggregate was a one size crusher-run stone having the following characteristics based upon a mechanical analysis: all the stone passed a 1¼-inch screen; not over 25 percent passed a 1¼-inch screen and was retained on a ¾-inch

FIG. 143. Upper Part, Water-bound Macadam. Lower Part, Bituminous Concrete Pavement, Class 1. A., without Seal Coat, Rhode Island State Highway.

screen; and not over 5 percent passed a ⅛-inch screen. With certain kinds of rock the percentage passing the 1¼-inch screen and retained upon the ¾-inch screen may be as high as 35 percent.

The State Board of Public Roads of Rhode Island has used Class 1. A. since 1906, see Figs. 142 and 143. The road metal was furnished under the following specification: "The bottom course shall consist of stone from 1¼ inches to 2½ inches in their longest dimensions, the upper course of stone from ½ to 1¼

inches in their longest dimensions." The product of the crusher which met this specification for the stone of the wearing surface was obtained from the ordinary type of crushing plant, the broken stone usually passing over a ¾ to ½-inch screen and through a 1½-inch screen. A mechanical analysis of a typical product used in Rhode Island is given below.

Percent	passing	10-mesh	screen	1.0
"	"	¼-inch	"	2.5
"	"	½ "	"	30.8
"	"	¾ "	"	34.2
"	"	1 "	"	23.4
"	"	1¼ "	"	8.1

In 1909 a series of experimental sections was constructed on a state road subjected to mixed traffic of about 100 horse drawn

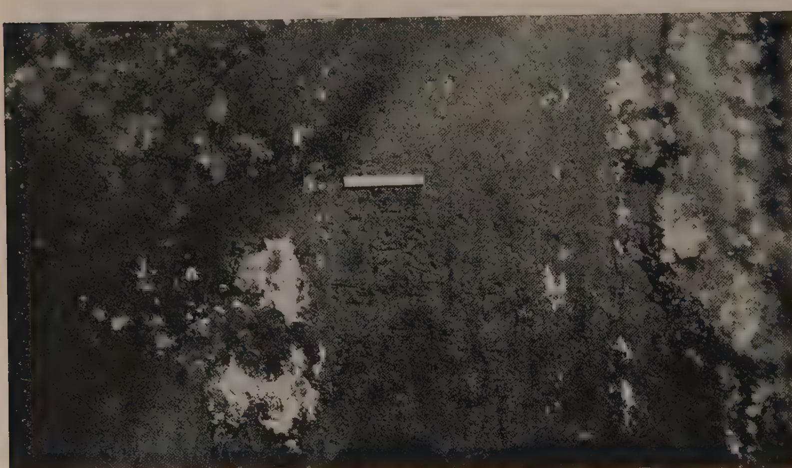

FIG. 144. Asphalt Seal Coat.

vehicles and from 250 to 300 motor-cars per day, many of the motor vehicles being of the large touring car type and traveling at high speeds. These experimental sections were constructed to determine the most economical and satisfactory bituminous material to be used for the cement in the mix and for the seal coat for bituminous concrete pavements subjected to the above class of traffic. Asphalt, refined water gas tar, refined coal tars, and

combinations of refined coal tars and asphalts were employed in the construction of the sections, the same material being used for the cement and the seal coat. The results secured from these experiments, based upon an examination in 1912, indicate that for this class of combination traffic or for horse drawn vehicle traffic exclusively, the seal coat should consist of an asphalt, see Fig. 144, as being more economical and efficacious than refined tar, see Figs. 145 and 146, or a combination of refined tar and

FIG. 145. Coal Gas Tar Seal Coat.

asphalt, see Fig. 147. (Ice covers a portion of the surfaces shown in Figs. 144, 145, and 147.) The same conclusion has been reached based on the results of experimental sections constructed in the Borough of Queens in 1911. In this particular instance a bituminous concrete, with tar used as the cement and seal coat, required retreatment with a seal coat in 1912, while the section constructed with tar as the cement and asphalt as the seal coat did not require a new seal coat.

The Quarrite-Bitulithic Company of London imports from its Scotland plant broken stone of various sizes, coated with bituminous material, for the construction in England of bituminous concrete pavements by the layer method. The sizes used for the courses are as follows: First course, 2 inches rolled of

1-inch to 1¾-inch stone; scattering of chips ⅛ to ⅜ inch in diameter; second course, 1 inch rolled of stone varying from ¼ to ¾ inch in longest dimensions; finished with a thin layer of tar-coated screenings.

As an illustration of the practice in Germany will be cited the work of the Deutsche Quarrite and Bitulithic-Pflaster-Gesellschaft of Berlin. In 1910 this company built a bituminous concrete pavement in Lankwitz, Germany, as follows: On a 5-

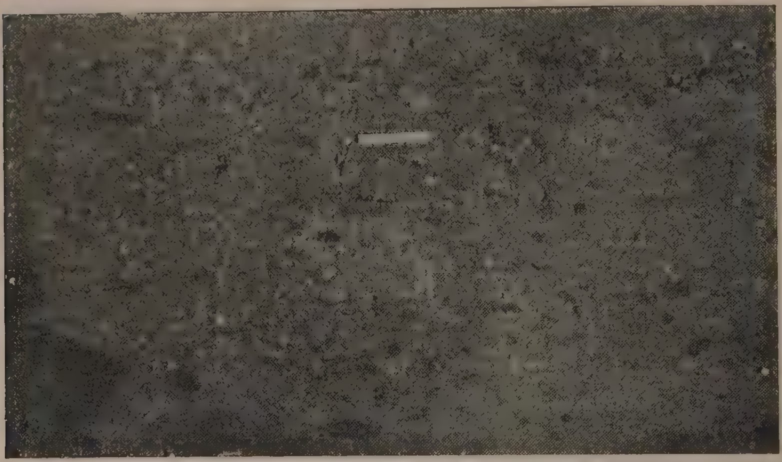

FIG. 146. Water Gas Tar Seal Coat.

inch macadam cinder-filled foundation the first course, consisting of 4 inches loose of 1½-inch tar-coated stone, was spread and rolled; a thin coat of tarred chips was next spread and rolled; the second course proper consisted of 1 inch of ¾-inch tar-coated stone, well rolled; the final course was ½ inch of tarred chips applied and rolled; the pavement was finished with a flush coat of tar on top of which were spread uncoated screenings.

In several countries of Europe the Aeberli system of constructing bituminous concrete pavements has been employed. By means of one machine, the one size crusher-run broken stone is dried, cleaned by a dust exhauster, and finally passed through a cold bath of crude tar. The tar-coated stone is then stored in piles and covered with a blanket of sand, 3 to 4

inches in thickness, for a period of from three to six weeks, in order to allow the light volatile oils of the crude tar to evaporate. At the end of this period the tar-coated mineral aggregate is used in the ordinary way for the construction of the bituminous wearing surface. Many failures have resulted from the use of this method due primarily to the unsatisfactory quality of the crude tar employed.

Specifications. Rhode Island. In 1912 the following specifications were employed in Rhode Island.*

"The stone for this course shall be ¼ inch to 1½ inches in

FIG. 147. Tar-Asphalt Seal Coat.

size and shall be dry and free from dust and dirt. The bituminous material will consist of refined coal tar furnished by the State Board of Public Roads at the railroad freight station nearest the site of the work, in tank cars of approximately 8,000 to 10,000 gallons capacity, fitted with steam coils.

"The tar shall be heated in kettles to a temperature of 200 degrees Fahrenheit, and mixed with the stone either by hand on dumping boards or by machine satisfactory to the engineer. Approximately 15 gallons of tar shall be used with each cubic

* See *Engineering & Contracting*, February 26, 1913.

yard of stone, and the whole mass shall be turned until the stones are thoroughly coated. The mixing shall be done at such place or places as may be agreed upon between the engineer and the contractor.

"After being thoroughly coated with the tar, the stone shall be placed upon the foundation or lower course prepared as hereinbefore described and thoroughly rolled satisfactorily to the engineer or inspector, with a roller whose weight shall not exceed 10 tons.

"After the course has been prepared as above described, a flush coat of about ½ gallon of tar or asphalt (to be furnished by the Board) to the square yard shall be applied to the surface, and clean sharp and dry sand free from loam, clay, and foreign matter of all kinds spread upon it to a depth of ½ inch. The whole surface shall then be rolled as directed by the engineer or inspector."

Specifications, Borough of Queens. The following excerpts from specifications which were drawn to cover a bituminous concrete of Class 1. A. laid in 1911 in the Borough of Queens, New York City, cover many essential features of this kind of construction:

"*Heating Bituminous Materials.* The bituminous material shall be placed in the kettles, so that while one lot is being used from one kettle, another lot will be heating ready for use. The temperatures to which the different materials shall be heated before being used are as follows: Cut-back oil asphalt for mixing to at least 250 degrees Fahrenheit and not above 300 degrees Fahrenheit; oil asphalt for penetration method and for seal coat only to at least 300 degrees Fahrenheit and not above 350 degrees Fahrenheit; fluxed native asphalt to at least 300 degrees Fahrenheit and not above 350 degrees Fahrenheit; refined tar to at least 225 degrees Fahrenheit and not above 250 degrees Fahrenheit.

"*Mixing.* The mixing machine shall be charged with materials and operated in accordance with the directions of the engineer or inspector. From 18 to 21 gallons of bitumen shall be mixed with each cubic yard of stone. The materials shall

remain in the mixer for a sufficient length of time to be thoroughly mixed to the satisfaction of the engineer or inspector. Care shall be taken to keep the inside of the mixing drum clean.

"*Laying and Rolling.* The mixed aggregate shall be taken from the mixer to the road by means of wheelbarrows or carts and shall be evenly spread on the foundation with rakes so that the thickness after rolling shall be 2 inches. The mixed aggregate shall be spread from dumping boards if carts are used.

"*Seal Coat.* After the wearing surface has been rolled sufficiently so that the wheels of the roller do not make any creases and the surface has been thoroughly cleaned, a flush coat of bituminous material, as specified, shall be applied to the surface. The flush coat shall not be applied unless the surface is absolutely dry in the opinion of the engineer or inspector. From 3/4 gallon to 1 gallon of bituminous material shall be used per square yard. The manner of applying the flush coat shall be as follows: The heated bituminous material shall be placed in an iron-bodied wheelbarrow, the barrow being kept practically full of the hot material while the same is being used. The bituminous material shall be applied to the road from the wheelbarrow by means of brooms in the amount specified above. The painted surface shall be immediately covered with a layer of 3/8-inch stone to a depth which is satisfactory to the engineer or inspector. At no time shall there be more than about three linear feet of the painted surface left uncovered. The surface shall be rolled as directed by the engineer or inspector."

In connection with the above work a Smith Hot Mixer was used. The specifications covering the application of the seal coat were not followed, as a Good Roads gravity distributor and Perfection pouring cans were used for this purpose. The method described in the specifications has been used in the construction of a seal coat on bituminous concrete pavements of this type on the Rhode Island and Massachusetts State highways.

Specifications, Road Board of England. In England a large amount of bituminous concrete pavement of this type has been constructed, using tar as the bituminous cement and for the seal coat. As indicative of current practice in England, the specifi-

cations adopted by the Road Board of England in 1911 are given in part:

"The thickness of the surface coating of tar macadam when consolidated by rolling should be from 2 to 3 inches, according to traffic requirements. For a greater thickness than 3 inches the material should be applied in two coats. The finished surface should have a cross fall of about 1 in 32.

"The aggregate of the new surface of tar macadam should be composed of broken stone of approved quality, or selected slag of approved quality, and should contain at least 60 percent broken to the size of 2½ inches, not more than 30 percent of from 2½ inches to 1¼ inches, and 10 percent of ¾ inch to ½ inch for closing. The last-mentioned size should be kept separate and used as top dressing during rolling operations. The stone used must be thoroughly dried before beng coated with tar. A 10-ton roller is a suitable size for use in most cases, but good results can be obtained by using a 6-ton roller and finishing with a 10-ton roller.

"In order to get the best results from the use of tar macadam, it is advisable to apply a coating of tar to the surface after the road has been used by traffic for several weeks. Stone chippings, crushed gravel, coarse sand, or other approved material (free from dust) not larger than will pass through a ¼-inch square mesh should be used for gritting in quantity not exceeding 1 ton for 300 to 350 superficial yards if grit is used, and 1 ton for 200 to 250 superficial yards if coarse sand is used."

Specifications, Amiesite. "This is a proprietary pavement, consisting of crushed stone or gravel, coated with an asphaltic cement composed of refined asphalt containing not less than 90 percent bitumen, and suitable fluxes to give the desired results.

"*First Course:* Shall consist of Amiesite made of mixed stone running from ½ inch to 1½ inches in size. This shall be spread in a uniform layer 3 inches deep, loose measurement, using blocks or strips to insure an even distribution of the material, then rolled once.

"*Second or Filler Course:* Shall consist of Amiesite made of ½-inch, ¼-inch, or less stone, spread in a uniform layer 1 inch

deep, loose measurement; the total depth of the two courses shall be 4 inches, loose measurement."

"*Surface Finish:* After rolling as above stated, the Amiesite is thoroughly free from moisture, a filler of clean sharp sand, free of loam or clay, shall be spread in such quantity and such thickness as will be required to fill any spaces between the units of the surface and then again rolled to a finished surface having the desired crown."

Class I. B. This type, that is one having an aggregate composed of one size crusher-run stone mixed with fine material such as sand, screenings, or material of a similar character, has been described many times in early technical literature. For example, the following description was published over thirty years ago: "The manner of preparing, treating, and laying the asphalt mass is as follows: He took asphalt, one hundred and twenty-five parts; petroleum-oil, twenty-five parts. These substances were melted and thoroughly incorporated together, and to this mixture he added, in a heated state, sand or powdered stone, 750 parts, and gravel or broken stone, also heated, 1,100 parts. The whole was then thoroughly mixed."

Pavements of this type have been used by many engineers. In Washington, D. C., under the direction of Captain Mark Brooke, of the Office of the Engineer-Commissioner, bituminous concrete pavements have been constructed in accordance with the following specifications covering the mineral aggregate: "The paving material shall be composed of crushed trap rock screenings, concrete sand, and mineral dust in the following proportions: Trap rock screenings, two parts; concrete sand, one part, and mineral dust, at least 5 percent of the above aggregate; mixed with asphaltic cement." The trap rock screenings referred to above varied in size from 1 inch to screenings and were devoid of dust. Detailed specifications were also given with reference to the character of the sand and the mineral dust.

Arthur S. Lewis, Assoc. M. Soc. C. E., describes the details of the construction of the excellent pavements of this type laid under his direction in Lincoln Park, Chicago, as follows:

"The mixture as used throughout the entire paving, during the past two years, and now adopted by us as standard, consists of ½-inch limestone, torpedo sand, and bank or building sand. Asphaltic cement to the extent of approximately 8 percent by weight of the mineral aggregate (exclusive of the seal coat, which runs 4 pounds per square yard) was used.

"After the mixture was raked to a depth of about 2½ inches, a 10-ton tandem roller, the wheels of which were 6 feet in width, was used to compress the top to about 2 inches deep. The rolling was continued longitudinally and diagonally until no further compression was possible, after which a squeegee coat of pure asphalt was spread, using about ½ gallon per square yard, this coat being spread as soon as possible after the rolling was done, and while the top mixture was still warm. This insured a perfect bond, and as soon as the heated asphalt was poured from buckets on the top it was immediately rubbed as thin as possible with a rubber squeegee. A thin layer of ¼-inch (all passing a ½-inch ring) granite screenings was then spread over the surface, these granite screenings being heated and all moisture driven off before spreading on the pavement. This was again rolled with the 10-ton tandem roller.

"This squeegee coating when first applied was not more than 1/16 inch in thickness. We find upon examining the pavements after a year's wear that a remarkable result has been accomplished. This coating, instead of wearing off, actually becomes thicker, absorbing and enveloping entirely the original layer of granite screenings, and absorbing as well any sand or dust tracked or blown upon the surface, so that after a year the rubbery cushion on the surface of the road is an intimate mixture of asphalt and fine particles of stone and dust. At night the lights along the boulevard reflect from the surface as though it were wet or shiny, but we find that instead of being slippery, the reverse is true—the rubbery surface, mixed as it is with fine gritty particles, affords an absolutely dustless surface, no sprinkling being necessary, as there is no dust. For sanitary purposes, however, these pavements are regularly flushed each night, washing them clean. In winter we have no trouble as regards

slipping or skidding, the gritty surface above referred to affording excellent tractive qualities."

Specifications, Pennsylvania. The State Highway Department of Pennsylvania adopted a bituminous concrete pavement of Class 1. B. to be used on certain highways during 1912. The main features of the construction of the wearing surface are covered in the abstracts here quoted:

"*Mineral Aggregate.* The stone to be used in producing the asphaltic concrete mixture shall be good, hard, durable granite, trap rock or limestone, and shall be the run of the crusher passing a 1½-inch ring and shall not contain more than 5 percent of dust. Clean, coarse sand shall be used as a filler in the proportions found necessary and approved by the engineer in charge.

"*Mixture.*

Crushed stone..................	53 to 62 percent.
Sand.........................	30 to 37 percent.
Asphaltic cement..............	8 to 10 percent.

which shall be heated from 275 degrees Fahrenheit to 375 degrees Fahrenheit and mixed in an improved mixer in such a manner as to coat thoroughly each particle of sand and stone in order to produce a uniform mixture. It shall be spread on the prepared roadway (at a temperature of not less than 225 degrees Fahrenheit) with hot iron rakes and thoroughly tamped and rolled.

"*Rolling.* The roller shall be of the tandem style and shall not weigh less than 20,000 pounds and shall be continued in steady operation as long as the asphaltic concrete will take any compression and in a manner to be approved by the engineer in charge.

"*Seal Coat.* As soon as possible after the rolling of the mixture is finished and while the surface is still fresh and clean, and, if possible, while warm, a seal coat of bituminous cement of proper consistency to be flexible when cold shall be spread over the surface. It shall be applied while at a temperature of from 200 degrees to 350 degrees Fahrenheit, depending upon the bituminous cement used, and evenly spread with rubber squeegees. Only a sufficient coat shall be spread to flush the surface voids

without leaving an excess. Immediately over this, a top dressing of torpedo sand, fine gravel or stone chips free from dust, which must be thoroughly dry and heated in cold weather, shall be spread and thoroughly rolled into the surface. A small surplus shall be left to be worn in or worn away by the traffic."

Specifications, Filbertine. The 1912 specifications of the City of Philadelphia contain under the heading "Filbertine" the following paragraphs descriptive of the wearing surface and its construction:

"*Mineral Aggregate.* The mineral aggregate in the 'Filbertine' mixtures shall be combined within the following proportions best suited for making a dense mixture:

Stone: ¾-inch hard crushed....	55 to 65 percent.
Sand: coarse to fine..........	35 to 45 percent.
Asphalt cement: 70 to 80 penetration....................	5 to 8 percent.

"The crushed stone, sand, and paving cement shall be heated to a suitable temperature and then thoroughly mixed together with suitable machinery or tools until all are in a homogeneous mass. It will then be spread upon the prepared foundation by suitable means to proper thickness and immediately compressed by a steam roller of at least 8 tons weight, or rammed with hot iron rammers where the steam roller cannot be used.

"The wearing surface as thus constructed will have a thickness not less than 2 inches after ultimate compression."

Class I. C. Specifications for pavements of this type call for mechanically graded aggregates of broken stone either alone or combined with sand with or without other mineral matter. From a historical standpoint reference is made to the description of the "Excelsior Pavement," as it includes the characteristic features of this class, namely, that "several sizes are mixed to form a close mass without cavities." This description is made up of pertinent abstracts from a book entitled "The Excelsior Pavement," the advertisement of which is dated 1871.

"The Excelsior Pavement consists of a broken stone, or McAdam base, covered with a concrete surface, which being

close, smooth, and coherent, presents but little resistance to travel, and permits no movement among the stones that compose it; therefore, scarcely any dust or mud is formed; its superiority over others is manifest.

"The resisting material may be sand for the surface, gravel or broken stone mixed with sand for the middle, and larger stone for the bottom, or bed; broken stone alone is preferred; sizes being chosen which best form a compact structure, smooth on top, and strong throughout. Small fragments are not generally required. Several sizes are mixed to form a close mass without cavities, the coarser stone being put beneath. This material should be carefully selected for its strength and resistance, and contain no dirt or other foreign matter.

"The sand, gravel, or broken stone (of different degrees of coarseness, as laid at or below the surface) should be sharp, clean and hard; the cement should be uniform, fluid and adherent during mixture; and the compound should condense and harden rapidly under manipulation; being composed of the greatest amount of rock, and the least of cement, which will form a mass most resembling stone itself.

"The resisting material for the covering is dried and heated in a hollow cylinder, which rotates over a furnace, about a stationary axis slightly inclined and bearing fixed arms for stirring. Fire being in the furnace, and the apparatus put in motion, the material enters into the revolving cylinder from a hopper at the upper end; here it is tumbled over and against the heated exterior, stirred by the fixed arms, slowly moved downward and discharged into another and similar machine where, meeting the hot cement flowing in a stream from the still, the two are incorporated together, forming a uniform bituminous concrete, thoroughly intermixed. The mixing, proportions and temperature may be controlled at will, by regulating the fire, the feed of material, the flow of cement, and the opening through which the concrete is discharged.

"Thus far the process should be conducted at a central point where heat and power can be economically applied, and from thence, the mixture conveyed to the road-bed and quickly and

evenly spread thereon for rolling. The work is done in regular order, without handling the concrete or its components; the hot cement from the still, and the heated stones from the dryer pass to the mixer, and the resulting compound is discharged into the carts, without intermission and consequent loss of heat.

"Ordinarily too much cement is used; 10 percent (that is, 20 gallons to 1 cubic yard of sand and stones), thoroughly intermixed, and the concrete well and quickly compacted, is enough; the cement may be more fluid, is easier worked, and the concrete is better than if, as is the practice, 15 percent or more were put in.

"The system here outlined, of preparing and laying the improved, or 'Excelsior Pavement,' may be modified to suit circumstances. It is claimed that by putting down the concrete while hot, under great pressure, the best pavement at least cost may be made, for thereby the resisting material is brought in most thorough and intimate contact while the cement is fluid; under conditions favorable to form, with the smallest quantity of cement, a strong and compact structure, without cavities to admit wet and frost."

In 1907 one of the authors discovered a printed specification in the Library of the American Society of Civil Engineers entitled "Specifications for the Excelsior Pavement." The following excerpt covers the description of the mineral aggregate:

"Broken stones are preferred for the whole pavement, and shall alone be used for the covering. The greatest dimension of stones for the base (except as hereinafter noted) shall be between 3 inches and ¼ inch, and for the covering between 2 inches and 1/20 of an inch; the sizes shall be mixed in proportion, varying with the size to form a close mass, which, when dry and compact, can absorb not more than 20 percent of water."

It is evident that the definition of bituminous concrete pavements of Class 1. C. covers many different combinations of sizes of road metal used for the mineral aggregate of the wearing surface. Some of the combinations in use will be described.

Specifications, Topeka. Since 1911 many thousands of yards of pavement of Class 1. C. have been laid under the so-called "Topeka" specifications. In the Borough of Richmond,

New York City, over 40,000 square yards were constructed in 1911 on a total of eighteen streets under the direction of Theodor S. Oxholm, M. Am. Soc. C. E. In 1912 contracts for over 100 miles were let in the Borough of Queens, New York City. A decree was signed in 1910 by certain city officials and representatives of the Warren Brothers Company covering the use of the "Topeka" mineral aggregate. The following quotation is from the decree to which reference has been made: "It appearing to the court that of the mineral matter used in the pavements actually constructed in the cities of Topeka and Emporia, Kansas, no particles of stone were used that would not pass a screen with openings ½ inch in diameter, and that less than 10 percent of the stone or coarse sand used would be retained upon a screen with openings ¼ inch in diameter, and the remaining mineral matter used being finer than ¼ inch; and it further appearing that pavements constructed by the use of mineral particles as above described do not infringe the claims of complainant's patent No. 727,505, sued upon in this case; . . . And it further appearing that the pavements as actually constructed in the cities of Topeka and Emporia, Kansas, do not infringe the claims of complainant's patent No. 727,505, sued upon in this case, and that any pavements hereafter constructed in substantial compliance with the following formula, to wit:

"Bitumen, from 7 percent to 11 percent.

Mineral aggregate, passing	200-mesh screen, from	5	percent	to 11	percent.
" " "	40-mesh screen, from	18	"	to 30	"
" " "	10-mesh screen, from	25	"	to 55	"
" " "	4-mesh screen, from	8	"	to 22	"
" " "	2-mesh screen, less than 10 percent.				

Sieves to be used in the order named would not infringe the claims of said patent."

Specifications, Spokane. While using the "Topeka" grading as the basis for the specifications, the City of Spokane calls for a more definite grading of the mineral aggregate, and furthermore for a sand having a particular grading. In addition to the specifications covering the gradings, those referring to the applica-

tion of the paint coat on the foundation and the details of construction are quoted.

"*Paint Coat.* Upon the surface of the foundation of Portland cement-concrete a paint coat shall be applied to bind or tie the surface coat to the foundation. For this purpose the surface of the cement-concrete shall in its preparation be well tamped and finished with as regular and uniform a surface as possible, with no depressions exceeding ½ inch deep and no loose rock on the same. The surface of the cement-concrete must be clean and free from dust and loose material of any kind, and must be absolutely dry. The paint used for this purpose shall consist of 62 degree Baumé naphtha and asphaltic cement as heretofore specified. The asphaltic cement shall be dissolved while soft and warm, in naphtha, in such proportions that the resulting paint will have a glossy surface after evaporation of the latter, but at the same time can be applied so as to form as thin a coating as possible. Approximately 240 pounds of asphaltic cement shall be mixed with 1 barrel of naphtha. Approximately 50 gallons of this paint should cover from 350 to 400 square yards of concrete surface. No more of the surface of the foundation shall be painted than can be covered with the wearing surface within five hours after the application. Care shall be used to keep the paint coat clean, and should any of it become dirty, a second coating will be required.

"*Bituminous Surface Mixture or Wearing Course.* The surface shall consist of asphaltic cement, inorganic mineral dust, sand, and crushed stone. The sand shall be clean and not of uniform size, but shall be graded as follows:

Passed 200 mesh..................................	3 to 8 percent.
Passed 100 mesh and retained on 200 mesh..........	9 to 16 percent.
Passed 80 mesh and retained on 100 mesh..........	9 to 16 percent.
Passed 40 mesh and retained on 80 mesh..........	25 to 45 percent.
Passed 10 mesh and retained on 40 mesh..........	10 to 30 percent.

NOTE—This sand the same as used in sheet asphalt pavement.

"The crushed rock to be used in the wearing surface shall be selected basalt, hard, and broken as nearly cubical as can practically be made, care being used to eliminate all porous and soft

rock. The crushed rock shall be so graded, and the sand added in such amount, that the following percentages of the aggregate shall pass sieves of the following square mesh per lineal inch:

Passed 200 mesh	4 to 8 percent.
Passed 100 mesh and retained on 200 mesh	5 to 10 percent.
Passed 80 mesh and retained on 100 mesh	10 to 20 percent.
Passed 40 mesh and retained on 80 mesh	15 to 30 percent.
Passed 10 mesh and retained on 40 mesh	25 to 40 percent.
Passed 4 mesh and retained on 10 mesh	15 to 40 percent.
Passed 2 mesh and retained on 4 mesh—less than 10 percent.	

Sieves to be used in the order named.

"To the above mineral aggregate shall be added from 7 to 10 percent of bituminous cement.

"The item designated as inorganic mineral dust passing a No. 200 sieve within the limits named herein includes fine sand passing a No. 200 sieve not exceeding 4 percent to 8 percent of the total mixture, and such 200-mesh mineral dust naturally self-contained in the refined asphalt.

"*Mixing.* The mineral aggregate and asphaltic cement shall be heated separately to about 300 degrees Fahrenheit. The maximum temperature of the sand at the mixers shall in no case be in excess of 375 degrees Fahrenheit at the discharge pipe. The Portland cement or other inorganic mineral dust shall be mixed with the hot sand in the required proportions, and then these shall be mixed for at least one minute with the asphaltic cement at the required temperature and in the proper proportions, in a suitable apparatus, so as to effect a thoroughly homogeneous mixture.

"The paving mixture prepared in the manner thus indicated shall be brought to the ground in carts or wagons at a temperature of not less than 250 degrees nor more than 330 degrees Fahrenheit. If the temperature of the air is less than 60 degrees Fahrenheit, the contractor must provide canvas covers for use in transit. It will then be thoroughly spread by means of hot rakes in such a manner as to give a uniform and regular grade, so that after reaching its ultimate compression it shall have a thickness as shown on the plans and required in the specifications. This depth shall be constantly tested by means

of gauges. The surface shall then be compressed by a steam roller. While still warm it shall be drifted with torpedo sand and re-rolled. If considered necessary, it shall be re-drifted and rolled again until thoroughly compressed. A steam roller shall be used weighing not less than 250 pounds to the inch run, the rolling being continued for not less than five hours for every thousand square yards of surface. The surface of the finished pavement shall present a true and uniform surface with no rolls or depressions exceeding $\frac{1}{4}$ inch from the true grade and cross section of the street."

Specifications, Asphalt Block. For many years a bituminous concrete having the essential features of the "Topeka" grading has been used in the form of asphalt blocks. The following specifications proposed by A. W. Dow, M. Am. Inst. Chem. Engrs., and F. P. Smith, M. Am. Soc. C. E., and slightly modified by Clifford Richardson, M. Am. Soc. C. E., were adopted in 1911 by the Association for Standardizing Paving Specifications:

"The size of the block shall be 12 inches long, 5 wide and 3 deep. Blocks exceeding the following limits of permissible variation from the above measurements will be rejected: Length from $11\frac{7}{8}$ to $12\frac{1}{8}$ inches, width from $4\frac{15}{16}$ to $5\frac{1}{16}$ inches, depth from $2\frac{15}{16}$ to $3\frac{1}{16}$ inches. The blocks shall be composed of asphalt cement, filler, and crushed trap rock or hard limestone.

"The filler shall be thoroughly dry limestone dust or Portland cement, the whole of which shall pass a 30-mesh per lineal inch screen, 85 percent shall pass a 100-mesh per lineal inch screen, and at least 66 percent shall pass a 200-mesh per lineal inch screen. Not less than 7 percent of this filler shall be used in the mixture from which the blocks are made. The crushed rock used shall be a good quality of freshly crushed hard trap rock or hard limestone free from all weathered and other soft material. It must be clean and free from any adhering dust, clay, or other foreign matter.

"The asphalt cement, dust, and rock shall be thoroughly mixed while hot in such proportions as to give a block containing not more than 8.5 percent or less than 5.5 percent of bitumen

soluble in carbon disulphide, and at least 12 percent of mineral matter passing a 200-mesh sieve.

"The block must receive a compression in the mould of not less than 2 tons per square inch and it must be manufactured at such a temperature that the materials will press together into a compact mass under the pressure applied, making a block having a density of not less than 2.5 specific gravity at 60 degrees Fahrenheit for trap rock and 2.35 specific gravity for limestone aggregate."

The 1911 specifications of the Borough of the Bronx, New York City, stipulate with reference to the mineral aggregate of asphalt block that "The crushed trap rock shall be clean and sound, and shall be the entire run of the crusher which will pass through a screen having circular holes ¼ inch in diameter. The shape of the stones shall be as nearly cubical as possible and shall be graded from the maximum size to dust so as to give a mineral aggregate with a minimum percentage of voids."

Specifications, Warrenite. The 1912 specifications of the Bureau of Highways of the City of Philadelphia give the following description of the "Warrenite" wearing surface which is based on information furnished by a representative of the Warren Brothers Company and is hence of special value as giving the views of that Company relative to the type of construction covered by the term "Warrenite."

"Upon the foundation prepared as above described shall be spread 2 inches of 'Warrenite' surface paving mixture, which shall consist of:

"(a) Stone (with or without the addition of sand) graded in the following proportions so as to give the wearing surface a useful degree of density, rigidity, inherent stability, and freedom from voids: Material passing 1¼ inch screen and retained on No. 2 sieve, 40 to 60 percent. Material passing No. 2 sieve and retained on No. 4 sieve, 10 to 20 percent. Material passing No. 4 sieve and retained on No. 10 sieve, 10 to 5 percent. Material passing No. 10 sieve and retained on No. 30 sieve, 10 to 5 percent. Material passing No. 80 sieve at least 25 percent of which

will pass a No. 200 sieve, 10 to 5 percent. The balance to pass No. 30 sieve and be retained on No. 80 sieve.

"(b) From 5 to 10 percent 'Warrenite' Cement as directed, sufficient in quantity to coat each particle and fill the voids remaining between the stones and conforming to the attached specifications for 'Warrenite' Cement."

Specifications, Bitulithic. Since the beginning of the 20th century a large amount of a proprietary pavement known as "Bitulithic" has been laid in the United States. As described by Fred J. Warren, the wearing surface, which usually has a thickness of about 2 inches after compression, is constructed as follows: "The mineral or stone part is dried and heated in a modern dryer and is then separated by screening with rotary screen into its sizes varying from fine dust, which is less than 1/200 of an inch in diameter, to the largest size used. The several sizes of stone are then mixed in predetermined proportions, so as to reduce the voids to about 10 percent, in a modern 'twin pug' steam power mixer, and the hot bituminous cement is added in the mixer in sufficient quantity to not only coat every particle and fill all of the remaining voids but with enough surplus to furnish to the mixture after compression a rubbery and slightly flexible condition."

Specifications proposed by the Warren Brothers Company covering the preparation of the mix and the construction of the wearing surface are cited.

"*Mineral Aggregate.* Upon the roughened surface of the concrete prepared as above specified there shall be laid the following wearing surface composed of hard, crushed stone, sand, and bituminous cement to have the thickness when compressed of 2 inches.

"In preparing the mineral aggregate for the above wearing surface the following method and apparatus shall be used: The maximum size stone should be about one-half the thickness of the wearing surface. The several grades and sizes of mineral aggregate shall be accurately measured in proportions previously determined by laboratory tests to give the best results, that is, the most dense mixture of mineral aggregate and one having

inherent stability, heated in a rotary mechanical heater, so designed as to keep each batch by itself until heated, and then pass into a rotary mixer; or the varying sizes of stone approximately proportioned shall be fed into an elevator terminating and discharging into a rotary dryer, and after heating, the stone shall be elevated and passed through a rotary screen having sections with various sized openings. The minimum screen opening shall be 1/10 inch and the maximum shall not be greater than 1½ inch. The difference in the width of openings in successive sections shall not exceed ¼ inch in sections having openings smaller than ½ inch and shall not exceed ½ inch in sections having openings greater than ½ inch. The several sizes of stone thus separated by the screen sections shall pass into a bin containing sections or compartments corresponding to the screen sections. From these compartments the stone shall be drawn into a weigh box, resting on a multi-beam scale. The several sizes of mineral aggregate, after being separately weighed or measured as above, shall be dropped into a 'twin pug' or other approved form of mixer. In the mixer bitulithic cement shall be added in sufficient quantity to coat all particles and fill such voids as remain unfilled by the proportionment of the mineral aggregate. The aggregate shall be so proportioned as to secure in the aggregate inherent stability, density, freedom from voids, and resistance to displacement, and a mixture which when combined with the bitulithic cement and compacted together will form a bituminous street pavement structure containing mixed mineral ingredients of such grades as to give the structure inherent stability, and one in which the largest and smallest pieces are associated with each other indiscriminately throughout the structure, and in which the plastic bituminous composition permeates the entire mass, uniting the various sized particles thereof; filling the voids and forming the wearing surface. If the crushed stone does not contain enough finely divided particles to fill the small voids in the aggregate the deficiency of these finely divided particles shall be made up by the addition of sand or other suitable fine mineral matter.

"*Mixing.* The mineral aggregate shall be heated and mixed

with the bitulithic cement at a temperature consistent with good workmanship. The whole mixture shall be hot enough when reaching the street to be capable of being spread and raked without difficulty and not so hot as to injure the bitulithic cement.

"*Construction of Wearing Surface.* After rolling the wearing surface, there shall be spread over it a thin coating of bitulithic flush coat composition, by means of a suitable flush coat spreading machine, so designed as to spread quickly over the surface a uniform thickness of flush coat composition. This spreading machine shall be provided with a flexible spreading band and an adjustable device for regulating, to any desired amount, the quantity and uniformity of flush coat composition to be spread.

"*Seal Coat.* There shall be spread over the flush coat composition, in at least two coats, fine particles of hot crushed stone, in sufficient quantity to completely cover the surface of the pavement. These stone chips shall be spread by means of a suitable stone spreading machine, so designed as to provide a storage receptable of at least 5 cubic feet capacity and to cover rapidly and uniformly the surface of the pavement with the desired quantity of stone. This spreading machine shall be provided with an adjustable attachment for regulating uniformly the quantity of stone spread at each operation. The hot stone chips shall be immediately and thoroughly rolled into the surface until it has become cool. The purposes of the flush coat composition and the fine particles of hot crushed stone are not only to fill any unevenness in the surface, but also to make the surface waterproof and gritty, thus providing a good foothold for horses."

CLASS 2. Mineral aggregates of this type are composed of gravel, either run of the bank or graded mixtures of gravel and sand. Unless finished with an adequate seal coat, the fine gravel of the surface is liable to be dislodged if the traffic includes horse drawn vehicles. It is also evident that the interlocking of broken stone upon which the stability of many types of pavements depends is a desideratum which is very difficult to obtain with a gravel aggregate.

A type used by the New York State Highway Department in 1912 has been described by Spencer J. Stewart, Assoc. M. Am. Soc. C. E.

"This pavement consists of a mixture of asphalt and gravel in the proportion of 1 cubic yard of loose gravel to an average of 20 gallons of asphalt, the gravel containing not less than 10 percent of clay. The gravel is bank run, the largest particle of which was 2 inches in its longest dimension, and containing sufficient fines to partially fill the voids.

"The gravel was heated in a mechanical revolving dryer to a temperature of over 225 degrees Fahrenheit, after which the asphalt, heated to not less than 275 degrees Fahrenheit, was added and the mixture placed in a revolving mixer and thoroughly agitated until all particles were thoroughly and completely coated with the bituminous material. The mixture, at not less than 250 degrees Fahrenheit, was then spread upon the prepared bottom course by use of shovels from dumping boards and raked to a uniform surface with hot rakes, after which it was rolled with a self-propelled roller weighing at least 10 tons until thoroughly consolidated.

"Upon this surface was placed ½ inch of gravel screenings, containing not less than 10 percent of clay, which was saturated with water and rolled thoroughly and continuously until a clay mortar had been obtained. This process filled all the surface interstices with a gritty and adhesive substance, which made the road practically 'non-skid.' The traffic in a short time drives away all surplus screenings, leaving a mosaic surface."

Class 3. A mineral aggregate of slag has been used to a considerable extent in England since 1900. Although laid by various municipalities, the largest amount has been used in connection with the construction of "Tarmac." One of the "Tarmac" plants is located at Wolverhampton, adjacent to that of a company producing large quantities of blast-furnace slag resulting from the manufacture of forge iron. The large moulds of slag are transported by small cars from the iron works on a narrow gauge track and dumped near the "Tarmac" works and allowed to cool. These large blocks are broken by sledge

hammers to a size suitable for the crusher, to which point the broken slag is taken by an inclined railway. It is crushed and screened into sizes varying from ¼ to 2½ inches and dropped into bins and thence into a mixing machine where it is mixed with a tar compound. Since the slag is warm even after it has been crushed, no heating preliminary to mixing is necessary. Ten gallons of tar are used to a ton of slag, and some pitch, rosin, and Portland cement are also added to the mixture. The mixed material is dropped from the mixer into flat cars and shipped to the point where it is to be used in construction.

A large amount of "Tarmac" has been used in the County of Notts. None of the roads are painted when constructed. They present an excellent non-slippery mosaic surface. The maximum grade on which this material has been used in this locality is 1 in 30. The roads are built on an earth subgrade in two courses of a total thickness of 4½ inches and with a standard crown of ¼ inch to the foot. The lower course is 2¾ inches in thickness, composed of pieces of slag ranging from 1¼ to 2½ inches in size, and the upper course is 1¾ inches in thickness, composed of pieces of slag ranging from ½ to 1¼ inches in size. The cost complete averages about 85 cents per square yard.

In certain cases more than two layers of bituminous coated slag are employed. The construction of one pavement of this type will be described. The location of the road was the main shore boulevard at Brighton-on-Sea on the south coast of England. The details of construction follow: On a well-compacted gravel foundation was spread a scattering of bituminous coated chips; the bottom layer, composed of 3½ inches loose of 1¼ to 2½-inch bituminous coated slag, was rolled; the second course consisted of 2½ inches loose of ½ to 1¼-inch bituminous coated slag, which course was thoroughly compacted; the third course was composed of ½ inch of ¼ to ½-inch bituminous coated slag chips, which layer was thoroughly rolled; the pavement was finished by rolling a top dressing of uncoated slag screenings. It may be of interest to note that an adjacent section on the King's Highway was constructed as above described in 1903.

Its condition in 1910 was excellent, while a macadam section of the layer type treated annually with an application of tar rapidly disintegrated before the close of each season.

Mechanical Appliances. To meet the demand for a mixing plant with which various types of mineral aggregates can be economically heated and mixed with bituminous material, several machines have been designed in the United States. The requirements of engineers vary to a considerable extent due to

Fig. 148. Smith Mixer without Heating Attachment.

the different kinds of aggregate employed; that is, in some cases, one size crusher-run stone is used; again combinations of broken stone and sand are employed; while in many instances a carefully graded aggregate is specified. The following machines have all been used in connection with the construction of bituminous pavements of one or more of the above types: the Smith Hot Mixer, the Rapid Heated Mixer, the Equitable Portable Asphalt Mixer, the Chicago Improved Cube Mixer with Austin Hot Mixing Attachment, the Koehring Hot Mixer, the Guelich Portable Asphalt Plant, the Iroquois Self-Propelling Asphalt Concrete Mixing Plant, the Link-Belt Portable Asphalt Plant, the Warren Brothers Company Portable Mixing Plant and the

Warren Stationary Plant, and the Ruggles-Coles Complete Drying, Heating, and Mixing Plant. In addition to these mixing plants, portable and permanent sheet asphalt mixing plants have been used, especially in connection with the construction of wearing surfaces of bituminous concrete pavements of Classes 1. B and 1. C.

Smith Hot Mixer. The Smith mixer, Figs. 148 and 149, is an ordinary Smith cement concrete mixer modified to meet

Fig. 149. Smith Hot Mixer.

the demands of the work. The mixer, boiler, and engine are all mounted on a four-wheel truck. The heat is passed into the mixer by means of a large iron pipe, which runs from the fire box to the outlet end of the mixer. A blower is attached to the fire box so that the hot gases can be forced through the pipe and mixer. An automatic loading skip is run by the same engine.

Rapid Heated Mixer. This machine consists of a cylindrical mixer mounted on a four-wheel truck. Heat is obtained from a hot-air jacket entirely surrounding the cylinder except on the ends and by means of a kerosene torch inserted within the drum. The power for the 1913 model is furnished by a 6 H. P. vertical engine and an 8 H. P. vertical boiler.

Equitable Portable Asphalt Mixer. The plant comprises a cylindrical mixing drum, hopper, elevator, boiler, engine, and oil heater, see Fig. 150. The aggregate is heated in the drum by means of a hot-air blast furnished by the oil burner.

Chicago Improved Cube Mixer, with Austin Hot Mixing Attachment. This plant consists of a cube mixer, see Fig. 151, with engine and boiler, an air compressor, a combination oil and air tank, an oil burner with a combustion chamber, and a charg-

FIG. 150. Equitable Portable Asphalt Mixer.

ing hopper. The hot air obtained by the combustion of the oil and air is led from the combustion chamber into the mixing cube. After the mineral aggregate is heated the bituminous cement is added.

Koehring Hot Mixer. The Koehring plant is similar in principle to the Chicago Cube Hot Mixing Plant except that a cylindrical mixing drum is employed in place of the cube mixer.

Guelich Portable Asphalt Plant. This plant consists of small storage hoppers for the different materials, a dryer, and a mixer. The mixing device in this machine is somewhat unique in that it is a cylinder which revolves around fixed paddles. This machine is furnished with a small engine capable of developing the requisite power for running the machine and has a fire box

by means of which heat is obtained for keeping the dryer and the mixer hot. It is mounted on four wheels and can be readily transported from place to place by a steam roller or other tractor.

Iroquois Self-Propelling Asphalt Concrete Mixing Plant. The Iroquois plant is mounted on a four-wheel truck and consists of an engine and boiler, a dryer, and mixer. The stone is raised by means of a chain elevator, passed through the dryer and

Courtesy of H. C. Poore.

FIG. 151. Chicago Cube Mixer.

out to the ground again, where it is raised by another chain elevator to hoppers placed over the mixer. The mixer itself is heated by a small steam jacket underneath the bottom. The mixer is of the same kind as used with sheet asphalt plants, that is, of the pug-mill type.

Link-Belt Portable Asphalt Plant. The Link-Belt machine is made in two sizes and mounted on four wheels for transportation purposes. The large machine is about 27 feet long and weighs approximately 17 tons. Practically all of the mechanism is housed in. It consists of melting kettles, a dryer, a dust blower, and a mixer. The material is shovelled into one end of the machine, passes through the dryer and thence into the

mixer, where it is mixed with the bituminous materials. The power for operating the machine is obtained by belting it to a road roller or a traction engine. The heat for the dryer, the melting kettles, etc., is obtained by means of fire boxes underneath the machine, in which coal is burned as fuel, the hot air passing around the various parts of the machine.

Warren Brothers' Portable Mixing Plant. The plant connected with the Warren Brothers' portable mixing machine

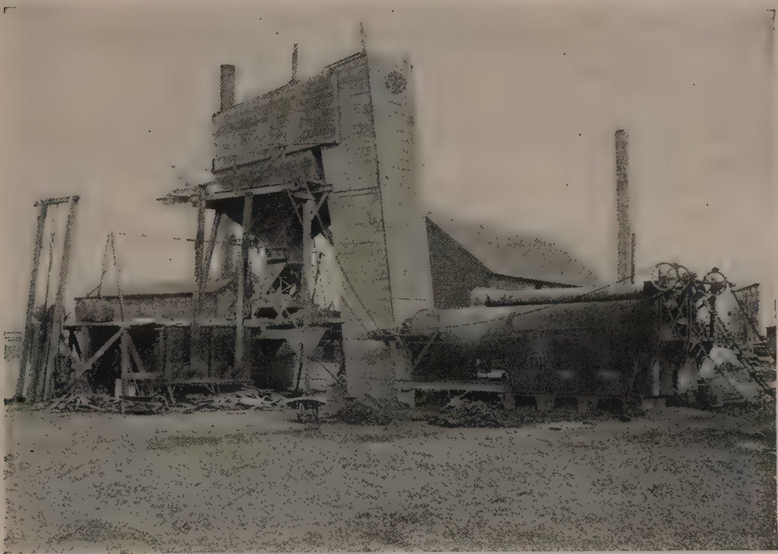

FIG. 152. Warren Brothers' Mixing Plant.

consists of a boiler, oil-burning apparatus, hoppers, elevators, dryer, and cylindrical mixer. In operation the measured aggregate is deposited in elevators which carry it to a storage bin from which it flows to a dryer and after a varying interval is dumped into the mixer. The bituminous material is introduced into the mixer above the discharge outlet.

Warren Brothers' Semiportable and Stationary Mixing Plants. In essentials the semiportable and stationary plants are identical. The plants comprise elevators for the delivery of the stone and sand to the cylindrical dryers, dust exhausters,

elevators for conveying the heated mineral aggregate to the revolving cylindrical screen composed of from four to six sections having holes of different sizes, hopper bins for the storage of the different sizes of the mineral aggregate, heating kettles, weighing devices for the bituminous cement and mineral aggregates, a pug-mill mixer, boiler, and engine. Figs. 152

FIG. 153. Weighing Device and Pug Mill Mixer, Warren Brothers' Mixing Plant.

and 153 show views of the plant used in 1908 in Providence, R. I.

Ruggles-Coles Complete Drying, Heating, and Mixing Plants. The plant consists of two units, one comprising a Ruggles-Coles dryer and heater, the other an elevator, stone bins, weighing bucket, measuring box for the mineral aggregate, mixer, engine, and boiler.

COST DATA. The cost of bituminous concrete pavements varies with the kind and quantity of bituminous material used, the character of the aggregate, and the method of construction employed. Using an aggregate of stone varying from ¼ to 1¼

inches in longest dimensions, mixed with 1.5 gallons of bituminous material per square yard and with a flush coat of 3/4 gallon per square yard, the cost for a 2-inch wearing surface would be about 30 to 35 cents in excess of ordinary macadam. The cost of pavements of Classes I. B and I. C varies from $1.00 to $2.25 per square yard, including foundation and light grading.

Class I. A. A comparison of costs of mixing one size crusher-run stone and refined tar by a Chicago Cube mixer and by hand mixing, see Fig. 154, has been compiled by H. C. Poore,*

FIG. 154. Hand Mixing of Broken Stone and Tar.

Jun. Am. Soc. C. E., based upon work done in Rhode Island in 1912.

"The following figures, based on careful observation of the various jobs, are a close approximation of the relative costs by the two methods:

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* *Engineering and Contracting*, February 26, 1913.

"No. 1.—Portable plant on resurfacing—2 inches thick.

440 square yards	Per day
Foreman, ½ time	$2.50
Engineer	2.50
6 laborers at $1.85	11.10
Kettle man	2.25
2 men spreading at $1.85	3.70
	$22.05

"This gives a cost of $0.05 per square yard.

"No. 2.—Hand mixing on board platform: Resurfacing—2 inches thick.

280 square yards	Per day
Foreman, ½ time	$2.50
10 laborers at $1.85	18.50
1 kettle man	2.25
	$23.25

"This gives $0.085 per square yard as the cost for labor of mixing and spreading.

"On the other hand, the machine mix costs are increased by interest and depreciation and the cost of installing and moving the plant."

Class 1. B. Linn White, Chief Engineer of the South Park Commission, Chicago, in describing the construction of bituminous concrete pavements of this type, cites* the following details of recording costs of operation of the Link-Belt Portable Asphalt Plant and the laying of the daily output which frequently amounted to 1,250 square yards of 2-inch surface.

"Our method of recording costs and results of daily work of asphalt plant crews may be of interest. The daily report of the asphalt plant foreman records:

1. Date.
2. Work number.

* See *Municipal Engineering*, February, 1913.

3. Location of work.
4. Total batches delivered by each asphalt plant.
5. Hours delay and cause.
6. Number and duties of each man employed.
7. Number of hours and rate per hour of each man.
8. Amount of asphalt used.
9. Amount and kinds of stone used.
10. Amount and kinds of sand used.
11. Amount of coal used.
12. Amount of gasoline used.

"In order to illustrate the data as to number, rate, and hours of men employed in the asphalt plant crew, I quote from the asphalt plant foreman's report on work order No. 2201 of July 1, 1912, as follows:

Number of men	How occupied	Rate	Hours
1	General construction foreman	55⅝	1
1	Asphalt plant foreman	33⅓	9
1	Traction engineer	55½	12
2	Firemen	29⅔	18
4	Asphalt cutters	25	36
4	Tankmen	25	36
6	Feeders	25	54
4	Mixers	25	126
2	Coal men	25	18
6	Men cleaning up	21⅞	54
4	Linemen	25	36
1	Oiler—machine tender	30	12
4	Carts hauling hot asphalt	50	24
4	Carts moving material	50	12
1	Team cleaning up	68¾	9
1	Timekeeper	33⅓	2
2	Timekeepers	27⅛	4
2	Watchmen	25	18
1	Water boy	12½	8

"The surface foreman's report on work order No. 2201 of the same date records:

1. Date.
2. Work number.
3. Location of work.
4. Thickness of asphaltic concrete laid.

5. Square yards of each thickness.
6. Number and duties of each man employed.
7. Number of hours and rate per hour of each man.
8. Total batches received from each asphalt plant.
9. Number gallons for squeegee.
10. Number cubic yards and kind of sand.
11. Number of pounds of coal.

"The surface foreman's report on work order No. 2201 of the same date also records:

Number of men	How occupied	Rate	Hours
1	Top foreman	40	9
4	Laborers raking	38	42
1	Laborer tamping back	38	10½
2	Laborers tamping	32	21
4	Laborers spreading	27	42
1	Laborer dumping carts	27	11½
1	Laborer painting joints	27	11½
1	Laborer spreading sand	25	10
1	Timekeeper	27½	2
2	Ten-ton rollers	55½	21½
1	General foreman	55⅝	1 "

Class 1. C. The cost of laying a "Topeka" asphaltic concrete pavement in Holland, Michigan, is given in the following quotation.*

"The paving proper consisted of 6 inches of Portland cement concrete and 2 inches of asphaltic concrete; the latter being the combination known as 'Topeka specification.' The material for the bituminous wearing surface cost as follows: Pioneer asphalt, 10.1 cents per gallon; stone (½ inch), $1.20 f. o. b. on the dock (average haul one mile); sand, 90 cents per yard. Teams cost $4.00 per day; labor, $2.00 per day on a nine-hour basis; and an inspector and foreman combined, $5.00 per day.

"Sixteen men were used in the concrete gang and thirteen men in the asphalt gang, the latter including the roller man and engine tender. Two 'Rapid' mixers were used, the same ma-

* See *Municipal Journal*, Vol. XXXIII, No. 24.

chines being used for both Portland cement concrete and bituminous concrete.

"The paving machinery having been purchased by the street fund, 6 cents per square yard was paid into this fund for the use of the machinery, or a total of $967.26. One hundred dollars was also paid into the same fund for the use of the city roller.

"The 6-inch concrete base was put down for 41.2 cents per square yard and the 2-inch asphaltic concrete top for 54.2 cents per square yard, making a total cost of pavement of 95.4 cents per square yard."

In Table No. 19 are given prices of "Bitulithic" constructed in several cities in 1911.

TABLE No. 19

From *Engineering and Contracting*, April 3, 1912.

City	Square Yards	Average Price per Sq. Yd. Including Base and Grading	Guarantee, Yrs.	Total Thickness, Ins.	Portland Cement Concrete Base.	
					Thickness Ins.	Proportions
Springfield, Mass.	9,886	$2.60	5	7	5	1-3 -5
Little Falls, N. Y.	7,300	2.65	5	8	6	1-2½-5
Newark, N. J.	119,961	2.13	5	8½	6	1-3 -6
York, Pa.	7,670	2.20	5	8	6	1-3 -6
Emporia, Kan.	34,000	1.48*a*	5	6	4	1-2½-5
Columbia, S. C.	16,837	2.12	5	7	5	1-3 -6
Bartlesville, Okla.	3,240	2.38	5	6	4	1-3 -6
Salem, Ore.	59,612	1.85*a*	5	6*b*	...	....

a Does not include grading.
b 4-inch broken-stone base, 2-inch top.

The cost per square yard of asphalt block pavements constructed in 1911 in several cities is given in Table No. 20.

Maintenance

The maintenance of bituminous concrete pavements is accomplished in a manner similar to that described in the chapter on Bituminous Gravel and Bituminous Macadam Pavements.

TABLE No. 20

From *Engineering and Contracting*, April 3, 1912.

City	Square Yards	Average Price per Sq. Yd. Including Base	Total Thickness, Ins.	Guarantee, Yrs.	Cement Concrete Foundation	
					Thickness, Ins.	Proportions
Johnstown, N. Y.	3,300	$2.55	7½	5	4	1-3-5
Newark, N. J.	4,409	2.78	9½	5	6	1-3-6
Niagara Falls, N. Y.	17,031	3.28	8½	5	5	1-4-7
Pittsburgh, Pa.	395	2.39	11	5	5½	1-3-6
Plattsburgh, N. Y.	2,194	2.40	8	5	3	1-3-6

Characteristics

Advantages. All of the advantages resulting from the construction of bituminous surfaces on macadam and gravel roads and of bituminous gravel and bituminous macadam pavements may be cited verbatim with reference to bituminous concrete pavements. Bituminous concrete pavements are usually more stable and durable than other types of roads and pavements in connection with the construction of which bituminous materials are used.

Disadvantages. First cost in certain cases may prohibit the use of bituminous concrete pavements. However, by the use of modern mixing plants, it is practicable to lay certain types of bituminous concrete pavements of Class 1. A. as economically as it is possible ordinarily to build a bituminous macadam pavement. Slipperiness with seal coats of some bituminous materials may occur and thus prove a disadvantage. It is evident that skilled supervision is required, which may be difficult to secure.

Causes of Failure. It should be noted that the percentage of failures of bituminous concrete pavements is much smaller than in the case of bituminous macadam and bituminous gravel pavements. Naturally failures may be considered from the standpoint of the materials employed and methods of construction adopted. Of course many failures have occurred because

the type of pavement used was not suitable for the traffic or other local conditions.

Materials. Poor and unsuitable materials have been accountable for certain failures. Attachment for a material of a certain class has led to the blind adoption of any material belonging to this class. Experiments in Rhode Island and in the Borough of Queens seem to have demonstrated that high carbon tar of a certain consistency is not as satisfactory or advisable for a seal coat as some types of asphalts, when the percentage

FIG. 155. Result of Using a Poor Grade of Tar.

and volume of horse-drawn vehicle traffic are large. In some cases an apparent cause of failure has been an excess of flux or of the volatile constituents in asphalt cements. Pavements constructed with such materials many times are wavy, due to the movement of the surface under heavy traffic.

Many of the above causes of failure would be eliminated if engineers would devote more time to a consideration of the physical and chemical properties of the materials which they

employ, see Figs. 155 and 156. Records should be at hand covering these data and details of the success or failure of every road noted. If a bituminous material laboratory is not connected with the department, it should not be either expensive or difficult to secure certified analyses made by reputable chemical engineers.

Either too large broken stone or stone of too uniform size may cause a failure. Especially is this the case with very hard and tough broken stone. The rocking of the stone causes the

FIG. 156. Failure Due to Bituminous Cement in Pavement.

formation of fine cracks which eventually lead to disintegration. Naturally the amount and character of the traffic are intimately connected with the condition of the pavement, but cases have occurred where failure, even under very light traffic, was due to using large uniform size broken stone for the mineral aggregate of the mix. Poor combinations of sizes of broken stone and sand have resulted in segregation during mixing, transportation, or spreading, resulting in a pavement of varying density and stability.

Construction. Many cases are reported where materials have been overheated at the construction site due to the belief

that all materials may be and even should be heated to the same temperature before using and that it is impossible to injure bituminous materials by heating to high temperatures. Overheating of the mineral aggregate has caused burning of the bituminous material in some instances or the formation of a thin film of bituminous material over the broken stone which is not of sufficient amount to bind the adjacent stones together. The use of a wet aggregate will usually result in a poor mix with consequent unsatisfactory results. In many instances the seal coat has been applied ununiformly. The result is either uneconomical, due to the necessity of a second application before 75 percent of the surface requires retreatment, or the disintegration of the pavement wherever bare spots occur in pavements where a coarse aggregate was used and where there is considerable horse-drawn vehicle traffic. Although of minor import to-day, some failures have been caused by using with unheated stone bituminous cements which will not adhere satisfactorily or which mix only with great difficulty under such conditions. Many failures are due to poor foundations. Sufficient attention has not been paid to this important part of the pavement.

Careful consideration of the causes of failures will result in material benefit, inasmuch as a comprehensive knowledge of the various causes of failure is one of the most valuable assets of engineers having in charge the construction and maintenance of bituminous surfaces and bituminous pavements.

CHAPTER XV

SHEET ASPHALT AND ROCK ASPHALT PAVEMENTS

In this chapter the types of bituminous pavement known as sheet asphalt and rock asphalt will be considered.

Sheet asphalt pavements are those having a wearing surface composed of a sand of predetermined grading, fine material or filler, and asphalt cement incorporated together by mixing methods. The wearing surface is usually laid upon a binder course of bituminous concrete which in the case of first-class pavements has been laid upon a cement-concrete foundation. The component parts of a sheet asphalt pavement are clearly shown in Fig. 157.

Rock asphalt pavements are those having a wearing surface composed of broken or pulverized rock asphalt with or without the addition of bituminous material.

Development. The first extensive use of rock asphalt for paving streets was in Paris in 1854, although there are records of its use for this purpose as early as 1838. From 1854 to 1867 considerable pavement of this kind was constructed, but it was not until 1867 that it was used on a large scale. The rock asphalt used in the first pavements was known as Val de Travers. Later another rock asphalt known as Seyssel rock was used with equal success. The first asphalt pavement in London was constructed in 1869, a Val de Travers asphalt rock being used. By the close of 1873 the total square yards paved with rock asphalt was about 61,000. The success of these early pavements led to the trial of this material in America, but the excessive cost of importing the material from Europe led to the development of the modern sheet asphalt pavement, composed of a thoroughly incorporated mixture of sand and asphalt. The first experiment with this type of asphalt pavement was tried out in Newark, N. J., in 1870. In 1876 Pennsylvania Avenue, Washington, D. C., was surfaced

with this material. This was the first real test on a large scale of the sheet asphalt pavement. Until 1882, however, only a few cities laid sheet asphalt, but from that time its use has increased so rapidly that it is now one of the most widely used and popular kinds of pavement. Although there are several rock asphalt

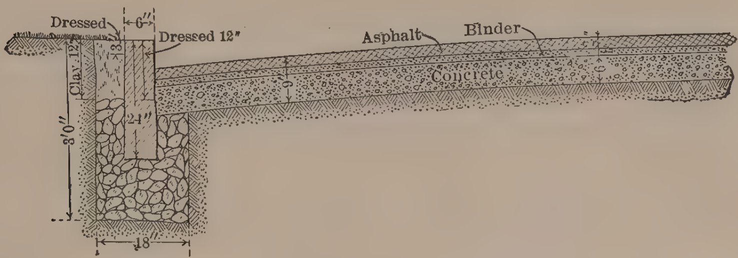

FIG. 157. Section Showing Construction of Sheet Asphalt Pavement in Pittsburg, Pa.

deposits within the borders of the United States, some of which would make a good pavement similar to those constructed in Europe, this material has never been used to any great extent. The freight charges in most instances would make the cost much more than that of the artificial mixture.

MATERIALS

ASPHALT CEMENT. The bituminous material which is used in the construction of sheet asphalt pavements is known as asphalt cement. In the trade it is commonly called A. C. The asphalt cements which are in use in the United States and Canada are described by the following definition:

Asphalt cement consists of asphalt, pure or mixed with foreign matter, which may or may not be fluxed with petroleum residuum.

In order to have a clear idea of the meaning of this term, the interrelationship of the terms covered by the following definitions should be considered.

Asphalts are solid or semisolid native bitumens, solid or semisolid bitumens obtained by refining petroleums, or solid or semisolid bitumens which are combinations of the bitumens men-

tioned with petroleums or derivatives thereof, which melt upon the application of heat and which consist of a mixture of hydrocarbons and their derivatives of complex structure, largely cyclic and bridge compounds.

Bitumens are mixtures of native or pyrogenous hydrocarbons and their non-metallic derivatives, which may be gases, liquids, viscous liquids, or solids, and which are soluble in carbon disulphide. This definition was adopted in 1912 by the American Society for Testing Materials.

Fluxes are fluid oils and tars which are incorporated with asphalts and semisolid or solid tar residuums for the purpose of reducing their consistency.

Many specifications for sheet asphalt pavements have included clauses covering the chemical and physical properties of "refined asphalt," "flux," and "asphalt cement." Furthermore, some specifications have covered the method by which the "refined asphalt" and "flux" should be combined in order to form the "asphalt cement." There is a marked tendency among some engineers and chemists to place emphasis upon the specification for the "asphalt cement." The fact that from so many well-known asphalts as "Bermudez," "California," "Pioneer," "Texaco," and "Trinidad" satisfactory asphalt cements, as shown by service tests, have been made, emphasizes the necessity of carefully considering the fundamental principles underlying the drafting of specifications for the asphalt cement. The above asphalt cements are derived from a variety of sources: the "Bermudez" and "Trinidad" A. C.'s are manufactured from the bituminous material obtained from deposits in Venezuela and Trinidad respectively, being combined after refining with a suitable flux; the "California" and "Texaco" A. C.'s are obtained by refining asphaltic oils and may or may not be fluxed; while the "Pioneer" A. C. is manufactured by combining the native bitumen, Gilsonite, with refined asphaltic oil. Having in mind the variety of methods which are used in the manufacture of asphalt cements during the present era and the complexity of each, it seems unwise to attempt to cover in specifications all the details of the methods employed in producing the cements.

Refined Asphalt and Asphalt Cement Specifications. As an example of an R. A. specification under which may be submitted either a refined asphalt requiring fluxing preparatory to use or an asphalt cement the 1912 specifications of Toronto, Canada, are cited.

"The refined asphalt as above obtained must meet the following requirements:

(a) It shall contain not less than 90 percent of 'Bitumen.' The word 'Bitumen,' as used in these specifications, shall signify and shall be taken to mean, 'any hydrocarbon or hydrocarbons, soluble in carbon bisulphide at air temperature.'

(b) Not less than 98.5 percent of its 'Bitumen' shall be soluble in carbon tetrachloride at air temperature.

(c) Not less than 65 percent of its 'Bitumen' shall be soluble in standard petroleum naphtha at air temperature.

(d) It shall not contain more than 15 percent of fixed carbon on ignition.

(e) Fifty grams of refined asphalt when heated in an open flat-bottom cylindrical dish, 2⅞ inches in diameter, and 1¼ inches high, shall not lose more than 5 percent of matter by volatilization at 325 degrees Fahrenheit in twenty-four hours.

(f) It shall not be softer than 60 penetration at 77 degrees Fahrenheit (Dow Machine).

(g) It shall not require more than 15 percent of flux, calculated on its percentage of 'Bitumen,' to produce an asphaltic cement of 45 penetration at 77 degrees Fahrenheit.

(h) The flux used in the preparation of the asphaltic cement above mentioned will be any suitable standard flux having a specific gravity at 60 degrees Fahrenheit between 0.9395 and 0.9722.

"The percentage of 'Bitumen' found by analysis of the sample submitted with the tender, shall be taken to be the minimum percentage of 'Bitumen' which the proposed grade of asphalt shall contain, and the award shall be made on the price per ton of 'Bitumen' calculated from the percentage of 'Bitumen' thus found."

Separate Asphalt Cement Specifications. The recommenda-

TABLE No. 21.

Properties	"Bermudez"	"California"	"Pioneer"	"Texaco"	"Trinidad"
Specific Gravity	1.0667	1.0453	0.9930	1.0083	1.2880
Melting point of normal material, in degrees Centigrade	61.0	59.0	77.0	64.0	62.5
Solubility in carbon disulphide, percentage	94.60	99.58	99.77	99.65	64.94
Organic matter, insoluble, percentage	3.46	0.22	0.12	0.10	5.33
Ash, percentage	2.94	0.20	0.22	0.25	29.73
Solubility in 88 degree Baumé paraffin naphtha, percentage	68.00	76.65	71.53	74.00	46.13
Fixed carbon, percentage	10.55	11.66	9.43	9.84	5.87
Viscosity, N. Y. T. L. viscosimeter	1′ 18″	52″	1′ 25″	1′ 11″	1′ 32″
Penetration of normal material:					
No. 2 needle, 200 grams, 0 degrees Centigrade, 1 minute	11	13	47	25	12
No. 2 needle, 100 grams, 25 degrees Centigrade, 5 seconds	50	70	78	55	50
No. 2 needle, 50 grams, 46 degrees Centigrade, 5 seconds	280	320	206	200	285
Evaporation 5 hours at 170 degrees Centigrade, percentage	3.0	1.4	1.2	0.25	2.3
Melting point residue, in degrees Centigrade	77.5	67	88	77	77.5
Penetration of residue:					
No. 2 needle, 200 grams, 0 degrees Centigrade, 1 minute	5	8	32	19	10
No. 2 needle, 100 grams, 25 degrees Centigrade, 5 seconds	21	27	58	38	21
No. 2 needle, 50 grams, 46 degrees Centigrade, 5 seconds	130	170	100	110	108
Evaporation 5 hours at 205 degrees Centigrade, percentage	7.8	2.8	4.3	0.75	7.1
Melting point residue, in degrees Centigrade	94	81	95	88	95
Penetration of residue:					
No. 2 needle, 200 grams, 0 degrees Centigrade, 1 minute	3	6	22	14	6
No. 2 needle, 100 grams, 25 degrees Centigrade, 5 seconds	8	15	35	29	12
No. 2 needle, 50 grams, 46 degrees Centigrade, 5 seconds	40	80	65	70	48
Flash point, N. Y. closed tester	170	...	195	232	205
Solubility in $C\,Cl_4$	94.60	95.58	99.77	99.65	64.94

tions of the Special Committee of the American Society of Civil Engineers, as quoted in Chapter XIV, which refer to the advisability of drawing separate specifications for each type of bituminous material to be admitted, are especially adaptable here. In other words, if "Bermudez," "California," "Pioneer," "Texaco," and "Trinidad" asphalt cements were to be admitted in competition, five independent specifications would be drawn, the limitations for each of the physical and chemical properties being drawn as close as practicable. To show the variability in the properties of asphalt cements which have given satisfactory results in service for a number of years, table No. 21 is given. The analyses are made in accordance with the methods of testing recommended by the Special Committee on "Bituminous Materials for Road Construction" of the American Society of Civil Engineers.

Inclusive Asphalt Cement Specification. If all of the above asphalt cements, with the exception of "Trinidad," were covered by a single specification the limitations might be specified as follows:

(1) The specific gravity at a temperature of 25 degrees Centigrade (77 degrees Fahrenheit) shall not be less than 0.975 nor greater than 1.075.

(2) Its solubility at air temperature in chemically pure carbon disulphide shall be at least 92 percent.

(3) The solubility of the bitumen, as determined under clause (2), in carbon tetrachloride shall not be less than 98.5 percent.

(4) The solubility of the bitumen, as determined under clause (2), at air temperature in 88 degree Baumé paraffine petroleum naphtha distilling between 40 and 55 degrees Centigrade (104 and 131 degrees Fahrenheit) shall be between 70 and 80 percent.

(5) It shall show between 8 and 13 percent fixed carbon.

(6) It shall show a flash point by the New York State Closed Oil Tester of not less than 180 degrees Centigrade (356 degrees Fahrenheit).

(7) It shall not vary from the following penetrations with a number 2 needle (Dow Standards).

100 grams, 5 seconds, at 25 degrees C. (77 degrees F.), 50 to 80

100 grams, 1 minute, at 0 degrees C. (32 degrees F.), Not less than 10

50 grams, 5 seconds, at 46 degrees C. (115 degrees F.), Not over 325.

(8) When 20 grams of the asphalt cement are maintained at a temperature of 170 degrees Centigrade (338 degrees Fahrenheit) for 5 hours in a cylindrical vessel 2½ inches in diameter, the loss shall not be over 5 percent. The penetration of the residue, when tested for 5 seconds, 25 degrees Centigrade (77 degrees Fahrenheit) with a number 2 needle weighted with 100 grams, shall not be less than 50 percent of the original penetration as determined under clause (7) at 25 degrees Centigrade (77 degrees Fahrenheit).

Binder Stone. The 1912 Specifications of the American Society of Municipal Improvements described in detail the characteristics of the mineral aggregate comprising the bituminous concrete used in the construction of the binder course.

"This shall be clean, hard stone, free from any particles that have been weathered, or are soft. It shall all pass a 1¼-inch screen. Not less than 85 percent of the stone shall pass this screen in its largest dimension, and of the remaining 15 percent, no piece shall have a larger dimension than two inches. The stone shall be so graded from coarse to fine as to have the following mesh composition (sieves to be used in order named):

Passing

10 mesh, 15 to 35 percent	Total passing 2 mesh, 25 to 50 percent	Total passing 1 mesh, 45 to 85 percent
2 mesh and retained on 10 mesh, 10 to 35 percent		
1 mesh and retained on 2 mesh, 20 to 60 percent	Total passing 1¼-inch mesh, 50 to 75 percent	
1¼-inch mesh and retained on 1 mesh, 15 to 55 percent		

"The above limits as to mesh composition are intended to provide for such permissible variations as may be rendered necessary by the available sources of supply and the character of the

work to be done. The mesh composition and character of the stone may be varied, within the limits above specified, at the discretion of the engineer, depending upon the kind of asphalt used and the traffic conditions upon the street or streets to be paved."

Sand and Filler for Wearing Surface. Sand should be clean, moderately sharp, free from clay, loam, or other impurities, and should not vary more than 5 percent from the following percent gradings, that is, 5 percent for the three combined gradings:

Passing	Heavy Traffic		Light Traffic	
Passing 200 mesh	0.0		0.0	
" 100 "	17.0	34 percent	10.0	20 percent
" 80 "	17.0		10.0	
" 50 "	30.0	43 percent	30.0	45 percent
" 40 "	13.0		15.0	
" 30 "	10.0		15.0	
" 20 "	8.0	23 percent	10.0	35 percent
" 10 "	5.0		10.0	

The character of sand and filler adopted by the American Society of Municipal Improvements in 1912 is as follows:

"**Sand.** The sand shall be hard, clean grained, and moderately sharp. On sifting it shall have the following mesh composition (sieves to be used in the order named): Passing

200 mesh 0 to 5 percent	
100 mesh and retained on 200 mesh, 10 to 25 percent	Total passing 80 mesh and retained on 200 mesh, 20 to 35 percent
80 mesh and retained on 100 mesh, 60 to 20 percent	

50 mesh and retained on 80 mesh, 15 to 40 percent
40 mesh and retained on 50 mesh, 10 to 30 percent
30 mesh and retained on 40 mesh, 8 to 25 percent
20 mesh and retained on 30 mesh, 5 to 15 percent
10 mesh and retained on 20 mesh, 2 to 10 percent
8 mesh and retained on 10 mesh, 0 to 5 percent

"On very light traffic streets a coarser sand may be used with the approval of the engineer, but in no case shall a sand be employed that contains less than a total of 15 percent passing an 80-mesh sieve, such total to contain not more than 5 percent (calculated on the original sand) passing a 200-mesh sieve, or a mixture of 75 percent of sand of the character above specified and 25 percent of stone screenings passing a ¼-inch screen and retained on a No. 10 screen may be employed.

"The above limits as to mesh composition are intended to provide for such permissible variations as may be rendered necessary by the available sources of supply and the character of the work to be done. The mesh composition and character of the sand may be varied, within the limits above specified, at the discretion of the engineer, depending upon the kind of asphalt used and the traffic conditions upon the street or streets to be paved.

"**Filler.** This shall be thoroughly dry limestone dust or dust from other equally satisfactory stone or Portland cement, the whole of which shall pass a 30 mesh per linear inch screen and at least 66 percent of which shall pass a 200 mesh per linear inch screen. The surface mixture shall contain from 6 to 20 percent of this filler, depending upon the kind of sand and asphalt used and the traffic conditions upon the street or streets to be paved."

Construction

Sheet Asphalt Pavements.

Subgrade and Foundation. It is essential that the foundation for sheet asphalt should be firm and unyielding as the weight of traffic must be carried by it. Usually, therefore, a 1:2:5 to 1:3:6 cement-concrete is used, being 4 to 6 inches in thickness, depending upon the amount of traffic and subsoil conditions. The concrete must be thoroughly set before the binder course is laid. Bituminous concrete has been used in a number of instances, in which cases the binder course is not needed. This type of foundation is not advised, since the bond between it and the wearing surface is so firm that the latter can only be removed

with difficulty when repairs are necessary, and, furthermore, the foundation is not sufficiently stable in most instances where sheet asphalt is economically employed. A 4-inch to 6-inch macadam coated with asphalt or coal tar has been used and also ordinary macadam, the depressions being filled with a mixture of stone and asphalt. This practice should not be followed.

Binder Course. Upon this foundation the binder course is laid so as to be 1 to 1½ inches deep after rolling, about 40 percent being allowed for compression. This course is usually composed of broken stone, sand, and asphalt cement or broken stone and asphalt cement. The material is brought on to the street at 200 degrees to 325 degrees Fahrenheit, depending upon the type of asphalt cement used, in covered dump wagons, deposited, and smoothed down with hot shovels and rakes, care being taken not to displace the stone aggregate. It is then compacted with a 5-ton to 8-ton tandem roller.

The American Society of Municipal Improvements adopted in 1912 the following specification which described in detail the method of preparation and laying of the binder course.

"*Preparation.* The binder shall be composed of stone and asphalt cement of the character elsewhere herein specified and mixed in proper proportions. If the stone does not contain the proper amount of material passing the ½-inch screen, the deficiency may be made up by the addition of gravel or sand. The stone and the asphalt cement shall be heated separately to such a temperature as will give, after mixing, a binder mixture of the proper temperature for the materials employed. The stone when used must be at a temperature between 200 and 325 degrees Fahrenheit. The asphalt cement when used must be at a temperature between 250 and 350 degrees Fahrenheit. The asphalt cement and stone shall be thoroughly mixed by machinery in such proportions that the resulting binder shall have life and gloss without an excess of asphalt cement and the mixing shall be continued until a homogeneous mixture is produced in which all the particles are thoroughly coated with asphalt cement.

"*Laying.* The binder mixture prepared in the manner

above described shall be brought to the street in wagons at a temperature between 200 degrees Fahrenheit and 325 degrees Fahrenheit and shall be covered with canvas covers while in transit. The temperature of the binder mixture within these limits shall be regulated according to the temperature of the atmosphere and the working of the binder. On reaching the street it shall at once be dumped on the concrete and then be deposited roughly in place by means of hot shovels, after which it shall be uniformly spread by means of hot iron rakes and then at once be thoroughly compacted by tamping or rolling. The depth of the finished binder shall at no place be less than 1 inch or more than 3 inches and its upper surface shall be parallel to the surface of the pavement to be laid. The surface, after compression, shall show at no place an excess of asphalt cement, and any spot covering an area of one square foot or more showing an excess of asphalt cement shall be cut out and replaced with other material. Smaller spots may be dried by the use of stone dust and smoothers. All binder that shows lack of bond or that is in any way defective or which may become broken up before it is covered with wearing surface must be taken up and removed from the street and replaced by good material properly laid in accordance with these specifications, at the expense of the contractor. No more binder shall be laid at any one time than can be covered by a two days' run of the paving plant on surface mixture. Binder when laid shall be followed and covered with wearing surface as soon as is practicable in order to effect the most thorough bond between the binder and the wearing course. The binder course shall be kept as clean and as free from traffic as is possible under working conditions. If necessary it must be swept off immediately before laying the wearing surface on it.

"No binder shall be laid when in the opinion of the engineer the weather conditions are unsuitable or unless the concrete on which it is to be laid is dry and has set a sufficient length of time.

"*Requirements.* The finished binder must contain from 5 to 8 percent of bitumen soluble in cold carbon disulphide and from 15 to 30 percent of material passing a 10 mesh screen, the percentage of bitumen to be regulated in accordance with the mesh

composition and character of the mineral aggregate of the binder and the percentage of material passing a 10 mesh screen to be regulated in accordance with the traffic conditions upon the street or streets to be paved."

Wearing Surface. The aggregate consists of a finely graded sand and a fine filler such as stone dust or Portland cement. Volcanic dust has also been used as a filler with satisfactory results. The wearing surface, consisting of the aggregate and the asphalt cement, is usually laid 1½ to 2 inches deep. The amount of bitumen used varies from 9 to 13 percent and the filler from 6 to 12 percent. It is brought on to the street at 280 degrees to 325 degrees Fahrenheit, depending upon the type of asphalt cement used, dumped and spread on the binder surface, and then tamped around all manholes, gutters, and curbs, and rolled with a tandem roller weighing 5 to 10 short tons. A continued rolling is very essential, as a constant kneading action is necessary for a well-compacted surface. Special care must be taken along street car rails to secure thorough compaction. Usually one to three courses of stone block or brick are laid next the rail. Eighteen to 24 inches adjoining the curb are often painted with hot asphalt cement to secure imperviousness to water.

The details of preparation and laying of the wearing surface are admirably covered in the following excerpts from the 1912 Specifications of the American Society of Municipal Improvements.

"*Preparation.* The wearing surface shall be composed of sand, filler, and asphalt cement of the character elsewhere herein specified and mixed in proper proportions. The sand and the asphalt cement shall be heated separately to such a temperature as will give, after mixing, a surface mixture of the proper temperature for the materials employed. The sand when used must be at a temperature between 250 degrees Fahrenheit and 375 degrees Fahrenheit. The asphalt cement when used must be at a temperature between 250 degrees Fahrenheit and 350 degrees Fahrenheit. The filler shall be added to the hot sand in the required proportions and the two thoroughly mixed. The

asphalt cement in the proper proportions shall then be added and the mixing continued for at least one minute in a suitable apparatus until a homogeneous mixture is produced in which all the particles are thoroughly coated with asphalt cement. The weights of all materials entering into the composition of the wearing surface shall be verified in the presence of inspectors as often as may be required and the engineer or his representative shall have access to all parts of the plant at any time.

"*Laying.* The surface mixture prepared in the manner above described shall be brought to the street in wagons at a temperature between 230 degrees Fahrenheit and 350 degrees Fahrenheit and shall be covered with canvas covers while in transit. The temperature of the surface mixture within these limits shall be regulated according to the temperature of the atmosphere and the working of the mixture, and the character of the materials employed. On reaching the street, it shall at once be dumped on a spot outside of the space on which it is to be spread. It shall then be deposited roughly in place by means of hot shovels, after which it shall be uniformly spread by means of hot iron rakes in such a manner that after having received its final compression by rolling, the finished pavement shall conform to the established grade and have a thickness of not less than — inches. Before the surface mixture is placed, all contact surfaces of curbs, manholes, etc., must be well painted with hot asphalt cement. After raking, the surface mixture shall at once be compressed by rolling or tamping, after which a small amount of cement shall be swept over it and it shall then be thoroughly compressed by a steam roller weighing not less than 200 pounds to the inch width of tread, the rolling being continued until a compression is obtained which is satisfactory to the engineer. Such portions of the completed pavement as are defective in finish, compression, or composition, or that do not comply in all respects with the requirements of these specifications, shall be taken up, removed, and replaced with suitable material, properly laid in accordance with these specifications, at the expense of the contractor. Whenever so ordered by the engineer, a space of 12 inches next the curb shall be coated with hot asphalt cement

which shall be ironed into the pavement with hot smoothing irons.

"No wearing surface shall be laid when in the opinion of the engineer the weather conditions are unsuitable or unless the binder on which it is to be placed is dry. The finished pavement must be well protected from all traffic by suitable barricades until it is in proper condition for use.

"*Requirements.* The finished pavement shall contain between 9.5 and 12.5 percent of bitumen soluble in cold carbon disulphide, depending upon its mesh composition and the character of the sand used and the traffic to which it is to be subjected, but in all cases sufficient asphalt cement must be used to coat properly all the particles of the mineral aggregate. It must also contain not less than 10 percent of mineral matter passing a 200 mesh sieve and not less than a combined total of 25 percent passing the 200, 100, and 80 mesh sieves. On streets of light traffic, when the engineer has approved the use of a coarser sand or mixture than that specified for general use, the surface mixture must contain not less than 6 percent of mineral matter passing a 200-mesh sieve and not less than a combined total of 18 percent passing the 200, 100, and 80 mesh sieves. The maximum amount of 200, 100, and 80 mesh material in the pavement will be regulated according to the kind of sand and asphalt used and the traffic upon the street on which the pavement is to be laid, subject to the maximum requirements elsewhere herein specified under sand and filler.

"The above limits as to mesh composition and percent of bitumen are intended to provide for such permissible variations as may be rendered necessary by the raw materials used and by the character of the work to be done. The composition of the wearing surface may be varied within the limits above specified at the discretion of the engineer, depending upon the kind of sand, filler, and asphalt used and the traffic conditions upon the street or streets to be paved."

In the construction of the wearing surface there are many details which should receive special attention. H. B. Pullar, Assoc. Am. Soc. C. E., in discussing the laying of sheet asphalt

pavements, called particular attention to the following points: "The mixture should be protected while in transit from the plant to the street and dumped some distance from the part of the road on which it is to be spread. All of the materials should be turned over before raking and any lumps should be broken up. The raking should be so thorough and so true to grade that it is unnecessary to go back after rolling and retouch the low and high places. The surfacing roller should be used as soon as the material has cooled sufficiently to allow it, especially in cold weather. This gives the initial compression and, if properly done, is of great assistance for the final rolling. The final rolling should be continued until the surface is thoroughly compacted, is smooth, and shows no sign of roller marks. It is too often the case that a fair amount of rolling is considered sufficient, and engineers, inspectors, and officials should insist upon the proper amount."

Inspection. The problems involved in the adequate inspection covering the construction of sheet asphalt pavements are dealt with as follows by A. W. Dow, M. Am. Soc. Chemical Engineers:*

"The various factors that go to make up an efficient inspection of the manufacture of sheet asphalt pavements are:

"First; carefully drawn specifications,

"Second; an efficient inspector,

"Third; intelligent supervision and loyal support of the inspector by the engineer in charge of the work,

"Fourth; prompt and efficient support from an intelligently conducted laboratory.

"*Specifications.* Specifications should be drawn as technically correct as is possible and be so clear that there can be no portion of them misunderstood by the contractor. Before the work commences there should be a conference between the contractor, the engineer in charge, and the inspector who is to be in charge of the work at the paving plant. Each portion of the

* See 1911–1912 Lecture by A. W. Dow before the Graduate Students in Highway Engineering at Columbia University.

specifications, taking up each step in the process of manufacture, should be discussed and a thorough understanding arrived at with the contractor. The specifications should contain provision for the rejection of materials and work that are not in compliance with the requirements of the specifications, and at the conference with the contractor there should be an understanding as to just what procedure the city would adopt in the event of his materials not being satisfactory.

"*The Inspector.* The qualifications of a good inspector are many. He should have a fair technical knowledge of the manufacture of asphalt pavements. He should be a close observer of human nature so that he can adopt a method of inspection which will cause the least friction with the men whom he is placed to watch."

Rock Asphalt Pavements.

European Practice. In Europe practically all of the asphalt pavements are constructed with a wearing surface of pulverized rock asphalt. The naturally impregnated rock is obtained from the Val de Travers, Seyssel, Vorwohle, Limmer, and Ragusa mines.

The method of construction employed in Europe is as follows: After the rock asphalt is pulverized, the powder is placed in slow revolving cylinders and subjected to a heat of from 250 to 280 degrees Fahrenheit, the object being to drive off the moisture. This powder is spread on a foundation to a depth of 2 inches or 3 inches, raked to make it even, and tamped with hot rams or tampers weighing about 12 pounds and finally rolled with a 10-ton roller.

American Practice.

Borough of Manhattan. The 1912 specifications of the Borough of Manhattan, New York City, allowed the use of rock asphalt under the conditions here cited.

"Should any of the rock asphalts be used, the material shall be a natural bituminous limestone or sandstone, or a mixture of the two, and shall be prepared and laid in the following manner: The lumps of rock, after being mixed in the proper proportions, shall be finely crushed and pulverized, and the powder passed

through a 20-mesh sieve. In case of the use of any asphaltic limestone, or of a mixture of an asphaltic limestone and an asphaltic sandstone, nothing whatever shall be added to or taken from the powder obtained by grinding the natural bituminous rock. Should it be proposed to use an asphaltic sandstone only, which contains more than 9 percent of natural bitumen, of such a consistency that the resulting pavement would prove too soft to sustain traffic, the material, if satisfactory in other respects, shall be made to conform with the requirements of section 62, by the addition of inorganic dust, in such manner and in such proportion as the Engineer may direct. The powder shall contain from 9 to 12 percent of natural bitumen.

"This powder shall be heated in a suitable apparatus to 200 degrees or 250 degrees Fahrenheit, and must be brought to the ground at a temperature of not less than 180 degrees Fahrenheit in carts made for the purpose, and carefully spread as specified for refined asphalt pavement, to such a depth that after having received its ultimate compression it will have a thickness of 2½ inches when laid on concrete. When the foundation is other than concrete it shall be laid on a 1-inch binder course as heretofore described, and the net thickness of the rock asphalt wearing surface after compression shall be 2 inches. The surface shall be rendered perfectly even by tamping, smoothing, and rolling with heated appliances of approved design."

Association for Standardizing Paving Specifications. In the 1911 Report of the Association for Standardizing Paving Specifications the method of utilizing rock asphalt in the construction of asphalt pavements in the United States is outlined.

"The bituminous rock or rock asphalt for use in the wearing surface must be ground to such a fineness that its mineral aggregate, after being freed from the bitumen by use of carbon disulphide, shall all pass a 4-mesh screen. The wearing surface made of the bituminous rock or rock asphalt must contain between 9.5 and 12.5 percent of bitumen soluble in carbon disulphide. The ground rock asphalt shall be heated separately to not over 350 degrees Fahrenheit or below 250 degrees Fahrenheit. These

heated materials shall then be combined and thoroughly mixed in an asphalt mixer in the required proportions to produce a wearing surface complying with the above specifications. The mixture prepared in the manner above described shall be brought to the streets in carts at a temperature between 225 degrees Fahrenheit and 325 degrees Fahrenheit and shall be laid as specified in the specifications for sheet-asphalt paving."

Broken Rock Asphalt. Rock asphalt is sometimes employed in the United States in a manner similar to that of using broken stone. One method of construction is to lay on the foundation course of broken stone a 2½-inch course of 1-inch to 2-inch stone and roll just enough to render firm. Broken rock asphalt, containing 7 to 10 percent bitumen, is then raked on from dumping boards to a depth of ½ inch and rolled in, and finally a second course 1 inch deep is laid and rolled; or the whole may be laid in one course 1½ inches thick. Old macadam roads may be resurfaced by first scarifying and then applying a course of crushed rock asphalt as in new construction.

This material has been employed to a limited extent by the New York State Commission of Highways. W. G. Harger, Assoc. M. Am. Soc. C. E., states the following conclusion based upon its use in New York.* "Kentucky rock asphalt, being a natural product, is liable to be uneven in quality. It is hard to handle in cold weather, gives a slippery footing during storms of sleet, and disintegrates in spots. The cost of top course has been approximately 70 cents per square yard."

MECHANICAL APPLIANCES.

Asphalt Plants. The essential features of plants at which the binder mixture and wearing-surface mixture are manufactured have been ably presented by Francis P. Smith,† M. Am. Soc. C. E. The following abstracts have been quoted from his address.

"In the manufacture of bituminous pavements by the mixing method, three distinct operations are involved; viz.,

"1. Drying and heating of the mineral aggregate.

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* See *Engineering News*, February 2, 1911.

† See 1911–1912 Lecture on "Mixing Plants for Bituminous Pavements" before the Graduate Students in Highway Engineering, Columbia University.

"2. Preparation and heating of the asphalt cement or bituminous cementing material.

"3. Mixing the hot mineral aggregate with the hot asphalt cement.

"In a properly designed plant, the machinery for carrying out each one of these operations must be capable of handling sufficient material to insure the required output.

"Let us first consider a sheet asphalt plant having a capacity of 2,000 square yards of 2-inch wearing surface per working day of ten hours. A square yard of surface mixture 2 inches thick when compressed will average 200 pounds in weight. The total weight of the output will therefore be 2,000 × 200 or 400,000 pounds. This mixture will consist approximately of:

Sand..................	79 percent
Dust or filler...........	10 "
Bitumen.................	11 "
	100 percent

"The different portions of the plant must, therefore, be capable of handling the following quantities of material:

Dryer.................	316,000 pounds	= 126.4	cubic yards sand
Melting Tanks..........	44,000 "	= 22	tons pure bitumen
Mixer.................	400,000 "	= 200	tons surface mixture

"In order to appreciate more fully just what is required of an asphalt plant, it will be necessary to consider briefly the kind of raw materials used in it and the conditions under which they are handled.

"*Sand.* While actual paving work is not usually carried on in rainy weather, it is nevertheless frequently necessary to run very wet sand through the dryer owing to its having been exposed to the weather or because freshly dredged sand is being used. Unless ample dryer capacity is provided, therefore, the output of the plant when using wet sand will be greatly reduced. Many pavements are laid late in the fall or in early winter and under these conditions much more dryer capacity will be required than in warm weather.

"*Asphalt Cement.* The asphalt cements in common use con-

tain from 60 to 100 percent of pure bitumen. In order to produce a pavement containing a fixed percentage of bitumen, it is necessary to use much more of an impure asphalt cement than of a pure one. Plants designed for use with impure asphalt cements will therefore require much greater melting kettle capacity than if pure asphalt cements were to be employed. There are a number of plants upon the market which, while admirably designed for use with pure asphalts, have far too limited a melting-tank capacity to permit of anything like their normal output being maintained if an impure asphalt is used in them.

"*Mixture.* The capacity of the mixer in a plant of the size under discussion is usually rated at 9 cubic feet. This means that the batch dumped into it contains 9 cubic feet of sand plus the other ingredients. Dry hot sand will average about 95 pounds per cubic foot. In accordance with the formula previously given and assuming that a pure asphalt cement is being used, each batch would, therefore, consist of the following:

Sand..................	855	pounds
Filler..................	108	"
Asphalt Cement.........	119	"
	1082	pounds

"It will take 370 batches of this size to turn out the required amount of surface mixture. In a ten-hour working day this means 37 batches per hour, or one batch every 1.62 minutes. Not less than one full minute with a mixer speed of 60 to 80 revolutions per minute should be allowed for actually mixing each batch of surface mixture. This leaves a total of only 37 seconds in which the mixer must be charged with the various ingredients and the finished mixture dumped into the wagon. With a well-organized gang and a properly working plant, twenty seconds is all that is necessary, but it can readily be seen that this is one of the points where seconds count. The mixer capacity of a plant is usually figured very closely, and this makes it more than ever necessary that the melting tank and dryer capacity should be ample to furnish a continuous and uninterrupted supply of hot sand and asphalt cement, as it is almost impossible to make up for delays at the mixer."

A complete plant includes a cold sand elevator, a dryer, a hot-sand elevator, a hot-sand storage bin with screen, an asphalt elevator, a flux tank, melting tanks, draw-off tanks, a sand-measuring box, a dust elevator, bin and measuring box, an asphalt cement bucket, and a mixer. In large plants agitation in the melting tanks is necessary in order to prevent burning, especially when the asphalt cement is heated by direct fire. Agitation may be accomplished by blowing air or superheated steam through the asphalt cement, or by mechanical means. In the case of asphalt cements containing considerable foreign material, it is advisable to use mechanical agitation or a combination of mechanical agitation and the injection of air or superheated steam in order to prevent the impurities from settling to the bottom of the melting tanks. The mixing device of this type of plant consists of a semicylindrical trough for holding the materials to be mixed together. A series of paddle wheels revolves on a horizontal axle which is fixed at either end within the trough. These paddles agitate the ingredients and thus produce the mix. The parts are all suitably arranged so that the operations follow one another in such a manner that none of the ingredients of the mixture have to be handled by hand from the time they are placed in the receiving end of the machine until they leave the outlet end.

Asphalt plants in use comprise three types: the permanent, semiportable, and portable plants. The last type is now placed permanently on flat cars as one or two car portable plants. During transportation the plant is housed, and when the car is drawn up on a siding the machinery may be rapidly prepared for work. Although varying in details, fundamentally all are similar, as the different parts mentioned are usually included. Asphalt plants of various types are manufactured by F. D. Cummer & Son, Hetherington & Berner, East Iron and Machinery Company, see Fig. 158, Equitable Asphalt Maintenance Company, Guelich Asphalt Plant Paving Company, Iroquois Iron Works.

The following estimate of the cost in detail of a small plant for the construction and maintenance of sheet asphalt pavements

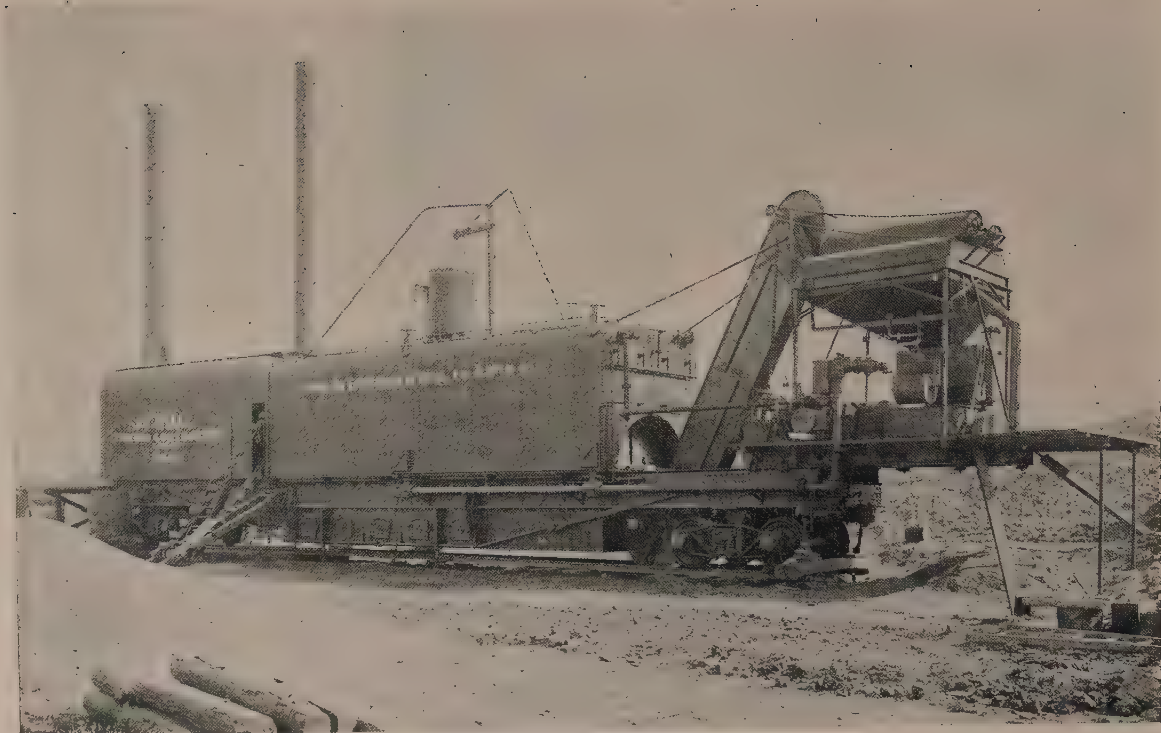


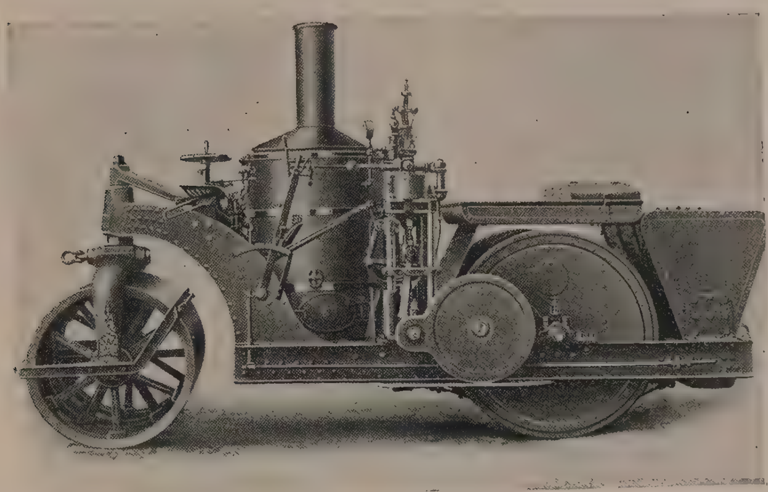
FIG. 158. One Car Portable Asphalt Plant of East Iron and Machinery Company.

has been compiled by J. B. Marcellus,* Assistant City Engineer of Boise, Idaho.

"1 Reheater	$300.00
6 Smoothers, at $3.50	21.00
6 Tampers, at $3	18.00
6 Axes, at $2	12.00
6 Sea-weed brooms, at $1.25	7.50
2 Camel-hair brooms, at $5	10.00
3 Picks, at $1.25	3.75
3 Asphalt buckets, at $1	3.00
1 Hand roller	50.00
	$425.25
Miscellaneous, 10 percent	42.52
	$467.77
Real estate	$500
Building	1000
Plant Machinery:	
1 Drum	500.00
1 Hot and cold sand elevator	100.00
1 Melting kettle	250.00
1 Mixer	150.00
1 Sand bin, 6 x 8	100.00
1 Screen	100.00
1 Motor	350.00
Etc.	450.00
	$2,000.00
Street tools:	
6 Smoothers, at $3.50	$21.00
6 Tampers, at $3	18.00
6 Axes, at $2	12.00
6 Sea-weed brooms, at $1.25	7.50
2 Camel-hair brooms, at $5	10.00
3 Picks, at $1.25	3.75
3 Asphalt buckets, at $1	3.00
6 Racks, at $1.50	9.00
12 Shovels, at $1.50	18.00
1 10-ton roller	2,000.00
	$5,602.25
Miscellaneous, 10 percent	560.22
	$6,162.47"

* See *Municipal Journal*, July 12, 1911.

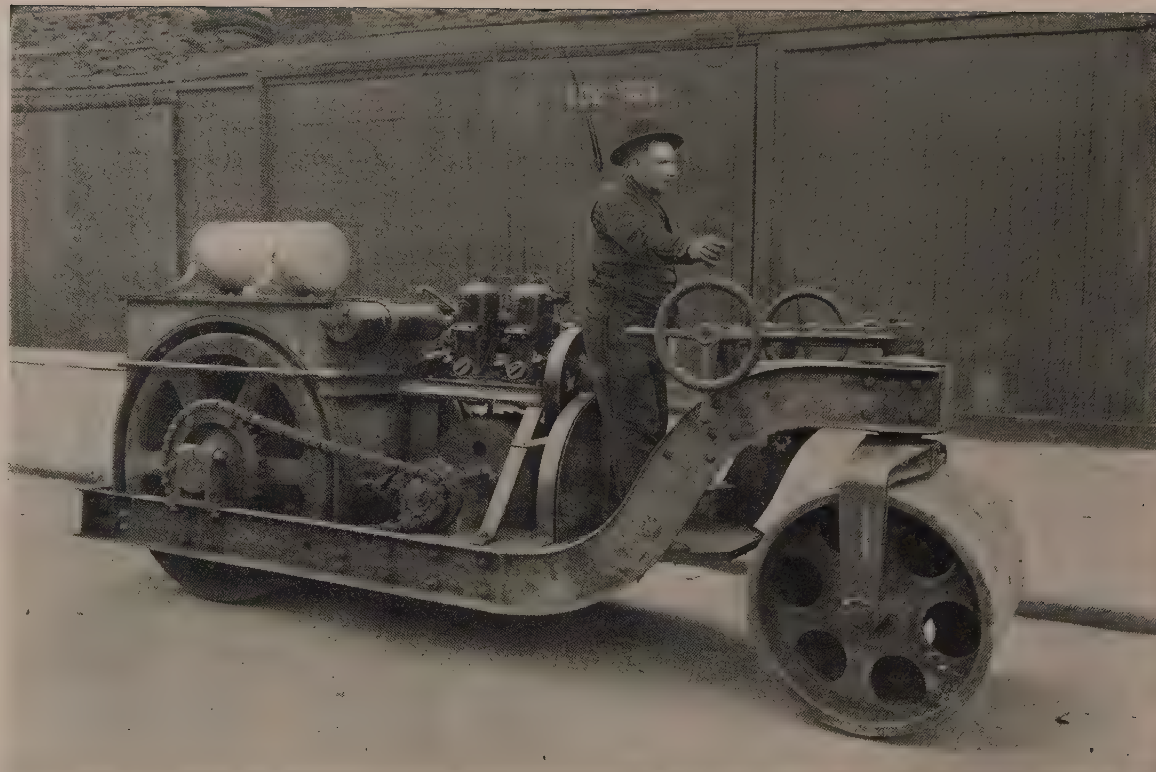
Tandem Rollers. This type of roller is used in the construction of sheet asphalt and rock asphalt pavements. Within the past few years the use of the heavy type of three-wheel rollers in constructing bituminous pavements of other types than those above mentioned has been found to be detrimental. Tandem rollers will in the future be more largely used on this type of work. Successful construction does not require the heavy weight so much as it does a steady rolling, which gradually brings the different particles of mineral matter together in juxtaposition without crushing them. The weight of the tandem rollers varies



Courtesy of the Buffalo Steam Roller Company.

FIG. 159. Tandem Steam Roller.

from 5 to 10 short tons. These rollers in the United States are commonly run by steam, see Fig. 159, although there are some makes, see Fig. 160, which are run by a gasoline engine. Rollers equipped with this latter power have been found to be particularly advantageous in the construction of rock asphalt pavements by European engineers: the rollers can be made more compact; no time is lost in waiting to secure steam; they are less noisy, are smokeless, and capable of much more rapid movement. The cost of tandem rollers varies from $1,300 to $2,800.



Courtesy of Charles Hvass and Company.

FIG. 160. Tandem Gasoline Roller.

Cost Data. The average costs of sheet asphalt pavements during 1911 with varying thicknesses of wearing surface, binder course, and cement-concrete foundation, are given in the following table:

From *Engineering and Contracting*, April 3, 1912.

	Square Yards	Thickness of Binder, in Inches	Thickness of Surface, in Inches	Ave. Price per Square Yard, Including Base and Grading	Guarantee, Years	Price per Cu. Yd. for Grading if paid for separately	Portland Cement Concrete Base.	
							Thickness, Inches	Proportions
Boston, Mass.	2,361	1½	1½	$2.00(a)	5	$0.50	6	1-3 -7
Schenectady, N. Y.	59,451	1	2	2.20(a)	5	.40	6	1-3 -6
Jersey City, N. J.	10,935	1	1½	1.90	5	.40	5	1-3 -5
Pittsburg, Pa.	30,588	1	2	2.15(a)	5	.50	6	1-3 -6
Fort Wayne, Ind.	31,424	1	1½	1.78(a)	5	.45	6	1-3 -6
Oshkosh, Wis.	8,523	1	2	2.90	5	...	6	....
St. Louis, Mo.	67,303	1½	1½	1.70(a)	5	.30(b)	5	1-4 -7
Washington, D. C.	17,745	1½	1½	1.70(a)	5	.55	6	1-3 -7
Oklahoma City, Okla.	276,231(c)	1½	1½	1.98(a)	5	.35	5	1-3 -5
Salt Lake City, Utah.	68,300	1½	2	2.30(a)	5	.80	6	1-3½-7
Portland, Ore.	536,090(d)	1	2	1.80(a)	5	.40	5	1-3 -6

(a) Does not include grading.
(b) 30 cents to $1.
(c) Cuban or Trinidad asphalt.
(d) Some of pavement is laid with 4-inch base, 1-inch binder, and 1½-inch wearing surface.

Maintenance

Sheet Asphalt Pavements. Failures of sheet asphalt pavements are usually due either to defective foundation, dirt on the binder, too soft asphalt in binder, frost, gas, kerosene or oil, fires, poor construction or lack of sufficient traffic to compact. The usual method of repairing sheet asphalt is to cut away the surface for a short distance about the affected spot and then strip it up from the foundation. The edges are cut down square and after being painted with asphalt cement, a new binder and surface mixture are laid as in new construction.

Explanations by Francis P. Smith,* M. Am. Soc. C. E., of several causes of deterioration of sheet asphalt pavements are given in the following excerpts.

* See 1912–1913 Lecture on "Maintenance of Sheet Asphalt Pavements" before the Graduate Students in Highway Engineering at Columbia University.

"The proper maintenance of an asphalt pavement involves the making of such repairs to it from time to time as are necessary in order that it may continue to render efficient service as a safe and smooth roadway or street.

"The deterioration which eventually renders these repairs necessary commences as soon as the pavement is laid and may be broadly classified under the following heads:

"1. Defects due to the wear and tear of traffic.

"2. Defects caused by the deterioration, through age and exposure, of the bituminous cementing materials used.

"3. Defects in construction.

"**Traffic Deterioration.** Under traffic the surface of the pavement is abraded and gradually wears off and the mineral particles exposed on the top are more or less crushed and broken. Where these particles are large, this crushing action is plainly noticeable, but with the smaller particles of sand it is hard to detect it. Under heavy traffic and unfavorable weather conditions, these crushed grains become active centers of disintegration. The crushed particles are not bound together by the asphalt cement and are soon swept away. The holes thus made in the pavement serve to retain the moisture and the edges of the holes are eventually more or less broken down, thus enlarging the hole. This condition reproduced all over the surface tends to make it wear away much more rapidly than would otherwise be the case. The effect of this action, which at first glance appears trivial, has been so well established by years of investigation and experience that it has become axiomatic in the paving industry that the heavier the traffic the finer must be the particles composing the mineral aggregate. In hot weather, when the pavement is plastic, the abrasion of the surface is much less than in cold weather, when the pavement is hard and possesses practically no plasticity. In hot weather the caulks on horses' shoes sometimes mark up the pavement to a very considerable extent, but the subsequent action of vehicular traffic wears these marks out almost completely. Nevertheless, in a community unaccustomed to sheet asphalt pavements, the appearance of these caulk marks in a new pavement is always regarded as an ominous

sign presaging its speedy destruction and failure. As a matter of fact, if the pavement, especially when newly laid, were not soft enough to show these marks, it would be an almost infallible sign that the asphalt cement used in it was too hard and that the total life of the pavement would be less than if a softer asphalt cement had been used. Traffic on a pavement always compresses it and increases its density and for this reason a two-year-old pavement will always mark up less than a new one. The pressure per square inch exerted by the comparatively narrow tire of a heavily loaded vehicle is much greater than that exerted by the heaviest steam roller used in the laying of sheet asphalt pavements. Even if this were not the case, the kneading action produced by narrow tires passing many times over the surface would always give greater compression than could be obtained by the action of the broad tires of a steam roller.

"When the traffic is confined to a comparatively narrow space and is always in the same direction, a distinct pushing force is exerted on the pavement. Whenever the pavement lacks inherent stability, due to an improper mineral aggregate or bitumen which is lacking in cementing value from natural causes or the rotting action of gas or water, or a combination of these defects, very distinct waves or bumps will be produced by the action of heavy traffic. These waves sometimes occur in recently laid pavements in which the asphalt cement used was of the highest quality, but in such cases will usually be confined to a few places. Investigation will almost always show defective binder in these spots, or too soft an asphalt cement, or too great a thickness of pavement owing to an error in the grade of the concrete.

"**Effect of Ageing and Exposure.** All bituminous materials used in paving work deteriorate upon exposure to the elements and to the rotting action of escaping gas, water, and street liquids. The lighter oils contained in them gradually volatilize, thus hardening the remaining bitumen. As the hardening process goes on, the pavement loses its plasticity and wears away with increased rapidity. Eventually the bitumen loses its elasticity and the pavement cracks. The edges of these cracks crumble away and the cracks become sufficiently wide to be plainly felt

by vehicles passing over them. The bumping action previously described in connection with waviness is produced and adds to the rapidity with which crumbling takes place. In order to guard against this and prolong the effective life of the pavement, the asphalt cement used in its construction is made as soft as possible without rendering the pavement too mushy when new.

"Some asphalts are more easily rotted by water action than are others. With such asphalts it is more than ever necessary to make the pavement as dense as possible to prevent the water from getting into it. Generally speaking, with all asphalts the wetter the climatic or other conditions, the denser and richer in bitumen should the mixture be made.

"The action of water upon a pavement may take place from the surface downward or from the bottom upward. The top surface is always compressed to its maximum density by the action of traffic, and if it has sufficient crown and grade to let the water run off and is kept clean so that it will not be covered by a layer of wet mud for long periods, but little deterioration will take place. Where water is allowed to remain in the gutters, the rotting will frequently be very rapid and this will be still more marked if, as in some towns, the dirty wash water from houses is discharged into the gutters. Too frequent washing of a pavement with water at a high pressure is also bad, as the abrasive action of such a jet is very considerable and acts in the same way as the stream from a hydraulic nozzle.

"Gas leaks produce a very similar result and the gas sometimes travels a long distance from the point of leakage before it actually comes in contact with the pavement.

"Another cause for the deterioration of sheet asphalt pavement is lack of traffic. Pavements laid on outlying residence streets and culs-de-sacs with little or no traffic, crack much more quickly than if they were subjected to a moderate traffic, which appears to be necessary to keep the life in the pavement. This is probably due to the fact that the surface is not in such cases kept at the maximum density by the action of traffic and gradually becomes porous, thus facilitating the evaporation of the lighter oils, and also to the fact that the kneading action of traffic,

like the continual use of a rubber band, tends to keep the life so to speak in the bitumen, and equalizes the stresses set up by contraction and expansion.

"**Defects in Construction.** Unless the foundation is rigid and of sufficient strength to carry the weight of the traffic passing over the finished pavement, no sheet asphalt wearing surface will give satisfactory service, see Figs. 161 and 162. Being plastic at all normal temperatures, the wearing surface will not

FIG. 161. Crack in Concrete Foundation Due to Poorly Drained Subgrade.

bridge over any depressions formed by the sinking or failure of the foundation but will sink with it. Assuming that the subgrade has been properly rolled and that the concrete is of the proper thickness and quality, the first point of importance is to see that it is laid to grade. If it is too high in places, the thickness of the binder and wearing surface must be reduced in order that the surface of the finished pavement may conform to the established grade. Any marked diminution in the thickness of the wearing surface will under heavy traffic considerably reduce the life of the pavement.

"Concrete laid in freezing weather will apparently set up when in reality it has frozen. When the hot binder and surface

mixture are placed on frozen concrete, the latter is thawed by the action of the heat and becomes mushy and has not sufficient strength to support the weight of the steam roller. Under such circumstances it is impossible to compress properly the hot mixture. In addition to this, the water set free by the thawing of the concrete is forced into the mass of hot material and more or less of it remains entrained in the mass.

"The best modern practice calls for the use of the tight binder, as it gives a much firmer foundation for the wearing

FIG. 162. Cracks in Curb and Sheet Asphalt Surface Due to Poorly Compacted Clay Subgrade.

surface and will not be broken up and loosened from the concrete by the passage over it of the teams hauling the hot surface mixture.

"Poor binder will break up very easily—sometimes it can be kicked up, and the hauling of the hot surface mixture over it will damage it very seriously. Surface mixture laid on a binder of this kind which has been badly broken up might almost as well be laid on loose broken stone and will not give satisfactory service under heavy traffic. The binder should of course be thoroughly compressed with a steam roller before laying the wearing surface on it. Lack of compression will produce an unsatisfactory

foundation for the wearing surface, and, as previously mentioned, binder which is too cold or made with too hard an asphalt cement or an insufficient quantity of asphalt cement cannot be properly compressed into a dense, tough mass. In hauling the binder to the street over long distances or in very cold weather, it may become chilled below the danger point. During the hauling process a certain amount of surplus asphalt cement usually drains off the stone and accumulates on the bottom of the cart or wagon. If these excessively rich portions be laid on the street, what are called rich or fat spots in the binder course will be produced. As the name implies, these are places carrying an excess of asphalt cement. If these are permitted to remain, the surplus asphalt cement will be absorbed by the hot surface mixture when it is placed over them. This will make a soft spot in the finished pavement which will be displaced by traffic and eventually produce a hole or depression in the pavement. They should, therefore, be cut out and replaced with normal binder.

"Before laying the surface mixture on the finished binder course, the latter should be dry and swept clean of dirt; otherwise the layer of wearing surface will not adhere properly to it. In many cases the loads of hot surface mixture are dumped directly upon the spot over which they are to be spread. This is bad practice, as the men trample upon it while shovelling and raking it and the rakes do not thoroughly loosen up this trampled material when passing over and through it. Although the mixture is raked to a uniform surface and apparently even thickness before it is rolled, those portions which have been trampled on before and during raking are really covered with a greater quantity of surface mixture than those portions which have not been trampled on and which are covered wholly with what might be termed loose or fluffy mixture. When the roller has completed its work there will therefore be a slight unevenness in the finished surface. Under light traffic this would make no appreciable difference, but under very heavy traffic the slight pounding action resulting from this condition would be detrimental and lead to uneven wear of the pavement. In those portions of the pavement which are inaccessible to the roller,

compression is effected by the use of hot smoothers or tampers, or both. If properly handled, the desired results will be obtained, but if used too hot, they will burn the pavement and cause it to scale or grind out.

"Extreme care should be taken to insure a proper union between the surface laid on successive days. The first loads laid in the morning at the termination of the previous day's work should be a little hotter than normal so that the hot mixture may soften the cold edge of the pavement and bond perfectly to it. The joint should be bevelled and freshly cut away unless the rope joint or a similar method is employed."

From the 1912 specifications of the American Society of Municipal Improvements the following quotations are taken which cover the methods to be used in repairing sheet asphalt pavements and the condition of the pavement at the end of the guarantee period which should be insisted upon.

"**Repairing.** Repairs, except as provided for below, shall in all cases be made by cutting out the defective binder and wearing surface down to the concrete and replacing them by new and freshly prepared binder and wearing surface made and laid in strict accordance with these specifications.

"Whenever any defects are caused by the failure of the foundation, the pavement, including such foundation, shall be taken up and relaid with freshly prepared material made and laid in strict accordance with these specifications.

"In all cases the surface of the finished repair shall be at the grade of the adjoining pavement and in accordance with the contour of the street.

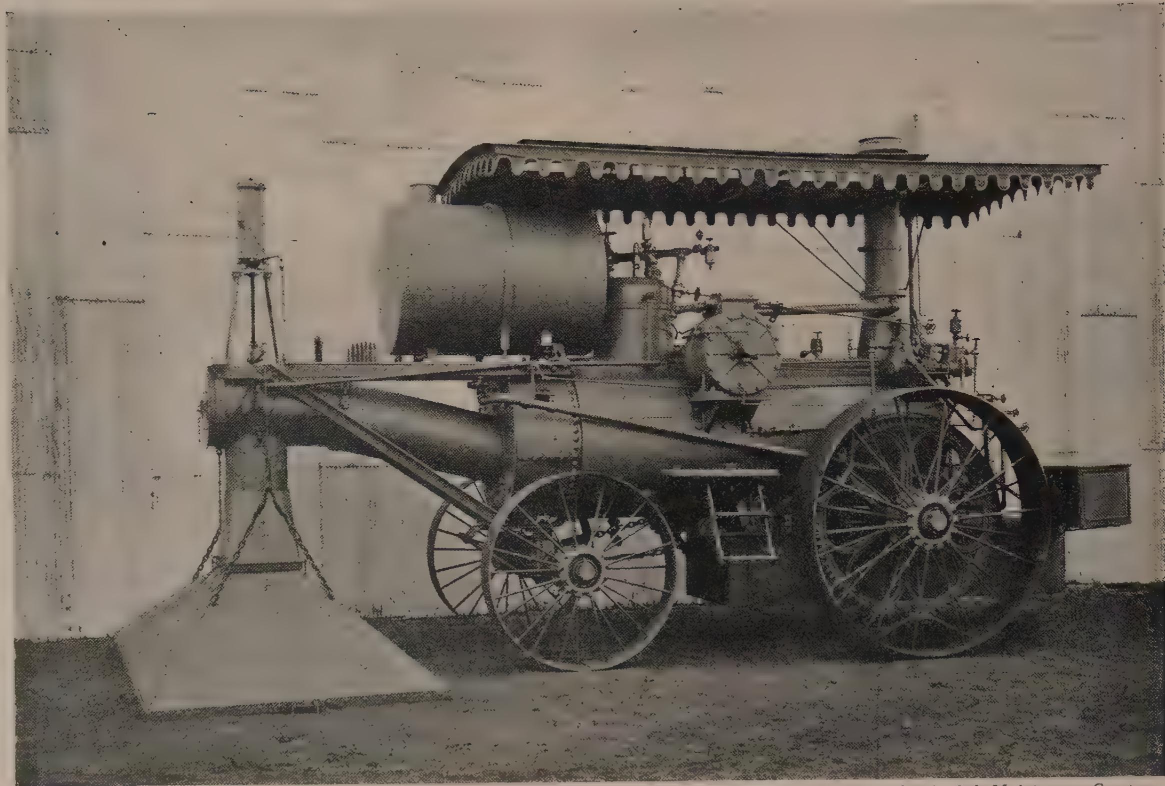
"The surface-heater method of repairing may be used only in those cases where the repairs are not rendered necessary by:

(a) Failure of concrete.

(b) Failure of the binder.

(c) Failure caused by the disintegration of the lower portion of the wearing surface.

"Whenever the surface heater, see Fig. 163, method is employed, all defective surface shall be removed before replacing it with new material. In all cases the old surface shall be re-



Courtesy of the Equitable Asphalt Maintenance Company.

FIG. 163. Lutz Surface Heater.

moved to a depth of not less than ¼ inch and the new surface must, when compressed, be not less than ½ inch in thickness. The heat shall be applied in such a manner as not to injure the remaining pavement. All burnt and loose material shall at once be completely removed and, while the remaining portion of the old pavement is still warm, shall be replaced by new and freshly prepared wearing surface made and laid in strict accordance with these specifications."

"**Conditions at Expiration of Guarantee.** In addition to the proper maintenance of the pavement during the period of guarantee, the contractor shall, at his own expense, just before the expiration of the guarantee period, make such repairs as may be necessary to produce a pavement which shall:

(a) Have a contour free from depressions of any kind exceeding ⅜ of an inch in depth as measured between any two points 4 feet apart on a line conforming substantially to the original contour of the street.

(b) Be free from cracks showing disintegration of the surface mixture.

(c) Contain no disintegrated surface mixture.

(d) Not have been reduced in thickness more than ⅜ of an inch in any part.

(e) Have a foundation free from such cracks or defects as will cause disintegration or settling of the pavement or impair its usefulness as a roadway."

Cost Data. Based upon experience in the construction and maintenance of sheet asphalt pavements in the District of Columbia for many years, the following conclusions * have been reached by the Engineering Department of the District.

"It is actually cheaper to maintain pavements at an average age of eleven years, resurfacing when the cost of patching becomes excessive, than it is to maintain them on a lower standard and of a greater average age. In order to bring the average age down to eleven years Congress has lately increased the appropriation, and in another year or two we shall have arrived at the point

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* See *Municipal Journal*, April 4, 1912.

where the pavements can be maintained with the maximum of economy. Very soon, when the average age of our pavements has been reduced to eleven years, we can compute by a simple formula the amount that will be required for asphalt pavement maintenance. A most careful study shows that we shall then need 10½ cents each year for each square yard of pavement in existence if we continue to operate under the contract system, or approximately 9½ cents per square yard per annum if we procure a municipal plant, following the example of the more carefully managed American municipalities.

"At the present time the prices paid for resurfacing and repairing asphalt pavements in Washington are as follows:

"Laying standard asphalt pavement (2½ inches asphalt surface, 2 inches binder before compression, with 6-inch concrete base), $1.68.

"Laying standard asphalt surface, 2½ inches before compression, 64 cents.

"Laying standard asphalt surface, resurfacing by the heater method, per cubic foot, 66 cents.

"Laying asphalt binder in connection with resurfacing work, per cubic foot, 28 cents.

"Laying standard asphalt surface for repairs, cuts, and miscellaneous work, 57 cents per cubic foot.

"Laying asphalt binder for repairs, cuts, and miscellaneous work, 43 cents per cubic foot.

"Laying standard asphalt surface for repairs, etc., within the space required by law to be kept in repair by street railway companies, 63 cents per cubic foot.

"Laying asphalt binder for repairs, etc., within the space maintained by the street railway companies, 48 cents per cubic foot."

Information relative to the yearly cost of maintenance of sheet asphalt pavements extending over a number of years has been recorded by the Bureau of Highways of the Borough of Brooklyn, N. Y. Typical examples are cited in the following table, No. 22, of pavements on which the guarantee has expired.

TABLE No. 22.

AVERAGE COST PER SQUARE YARD FOR REPAIRS.

Street	Kind of Asphalt	Date of Acceptance	1903	1904	1905	1906	1907	1908	1909	1910
Albany Avenue..	Trinidad Pitch Lake on concrete........	Dec. 3, 1897....	.029	.019	.021	.021	.042	.064	.086	.118
Arlington Place..	Trinidad Pitch Lake on concrete........	July 9, 1896....	.000	.002	.000	.000	.000	.027	.000	.044
Baltic Street....	Alcatraz on concrete..	July 25, 1896....	.053	.105	.070	.204	.118	.131	.064	.089
Berry Street.....	Trinidad Pitch Lake on concrete.......	July 16, 1897....	.186	.148	.152	.058	.204	.184	.231	.104
Cambridge Place.	Bermudez on concrete.	July 11, 1896....	.000	.001	.000	.000	.010	.020	.051	.075
Columbia Heights	Alcatraz on concrete..	Nov. 18, 1895....	.401	.009	.071	.055	.000	.393	.016	.116
8th Avenue......	Alcatraz on concrete..	Aug. 21, 1895....	.183	.659	.140	.136	.141	.248	.059	.111
1st Place,.......	Trinidad Pitch Lake on wood.........	Feb. 15, 1889....	.406	.252	.125	.342	.213	.366	.137	.180
Lafayette Avenue	Trinidad Pitch Lake on granite........	Oct. 9, 1888....	.468	.079	.054	.060	.104	.076	.150	.576
Park Place......	Trinidad Lake on cobble...........	Aug. 26, 1889....	.041	.231	.036	.087	.170	.206	.141	.069

CHAPTER XVI

WOOD BLOCK PAVEMENTS

Development. Russia is credited as being the first country to use a pavement constructed with wood blocks. Although wood has been used in this country in the construction of both corduroy and plank roads, neither type could hardly be called a wood pavement. The first wood block pavements in this country were laid in New York and Philadelphia about 1835, in England about 1838, and in Paris about 1880. The blocks first used were round or hexagonal in shape. Round cedar block was extensively used in the Middle West some years ago. The patent office contains many records of different types of wood block pavements that were patented at different times between 1840 and the present. One of the first methods in which rectangular blocks were used was the Nicholson pavement. This pavement was laid in many cities of this country, between 1860 and 1870, and was perhaps the most successful wood pavement up to that time. The blocks, which were 3 inches thick and 6 inches long, were laid in parallel courses with 1-inch joints on a plank sub-base and the joints were filled with hot gravel and coal tar. Little care was taken in selecting the wood for the blocks, and it was not until 1872 that a concrete foundation was used. In the development of this type of pavement, it was found that the rectangular block was the best shape to use, while other details of construction, such as proper foundation and joint fillers, were found to have a direct bearing on the success of the pavement. It has also been satisfactorily proved that unless the blocks are treated by some preservative process, the life of the pavement is considerably shortened. The success of the present type, which has been developed by the gradual improvement of the early methods of construction, is evidenced by the large amounts that have been laid in London, Paris, and

the United States. It has been extensively used in many of the largest cities of this country, among which might be cited the following: Greater New York, Boston, Chicago, Minneapolis, Detroit, Cincinnati, Toledo, and Indianapolis. It has also proven to be an excellent pavement for surfacing the roadways of bridges, many instances of which can be found.

The Wood

Woods Commonly Used. Very little thought was given to the kind of wood used in the earlier types of wood pavements, and without doubt this fact hastened the failure of many of the pavements constructed. The "Nicholson" pavement was sometimes constructed of blocks made of soft pine. The round blocks with which the streets of Chicago were largely paved in the early days of the city were cedar. Among the other woods which have been used in various cities of the United States may be mentioned oak, cypress, hemlock, Washington red cedar, cottonwood, mesquite, Osage orange, redwood, Douglas fir, tamarack, long-leaf yellow pine, short-leaf pine, Norway pine, and black gum. A great many of the wood pavements in England are constructed with Swedish deal. Experiments have also been tried there with camphor wood from Borneo, oak, beech, and both Australian and American red gum. The Australian woods, jarrah and karri, which are extremely hard and dense, were first used in London about 1891. They are only used to a slight extent now in England, the softer woods being preferred. The wood pavements of Australia, however, are largely constructed of jarrah, which is one of the principal woods of that country. In France, pine of Landes and of Gascogne are used to a great extent. Red pine of Nord, or Sylvestre pine, commonly but improperly called red fir of Nord, is also used. Little attention was given to the proper seasoning of the wood used in the earlier pavements, and only in rare instances were the blocks treated with any kind of materials which serve to preserve the wood. The importance of these things has been realized in the development of the modern wood pavement so that

today very few blocks are laid which are not made from carefully selected wood and subjected to some preservative process.

Experience has shown that there are only a few woods in this country with which it is commercially possible to make good blocks. Specifications differ slightly, but the best practice admits the use of southern yellow pine, long-leaf yellow pine, Norway pine, tamarack, and black gum. Below is given an excerpt from the 1912 Specifications of the American Society of Municipal Improvements.

"The wood to be treated shall be commercial yellow pine, Norway pine, or tamarack, only one kind of wood, however, to be used in any one contract. The blocks must be cut from good grade timber, namely: All timber must be sound and free from red heart, well manufactured, saw-butted, all square edge, and shall be free from the following defects: unsound, loose and hollow knots, worm holes and knot holes through shakes and round shakes that show in the surface. In yellow pine timber the annual rings must not average less than six to the inch, measured radially from the heart so as to include the greatest number of rings possible, and in no case in any one inch of this radius shall there be less than four annual rings. Wherever, in any one inch of this radius, there are less than five annual rings, the cross-sectional area of each resin ring shall be not less than 20 percent of the total cross-sectional area of its corresponding annual ring. The blocks must average 80 percent of heart wood, and no one block shall be accepted that contains less than 50 percent heart wood."

Omitting the last two sentences of the above specification, it becomes almost identical with the specification adopted in 1912 by the Association for Standardizing Paving Specifications.

Causes of Decay. The decay of wood is due to a low form of plant life called fungi. The fungi attack the wood from the outside, and if the wood is in the right condition for the spore to grow, they will ultimately penetrate the entire structure of the wood. There are three classes of fungi, one of which attacks all parts of the wood structure, another attacks the cellulose, the third, which is the most common, attacks only the lignin,

which is the name of the many organic substances which are incrusted around the cellulose. The fungi dissolve the lignin and the cellulose and make food for their development. Heat, air, and moisture are also necessary to the existence of the fungi growth. Without either one of these elements the fungi cannot live.

Wood Preservation. Since air and heat, in most climates, are ever present, it is necessary to eliminate the moisture as the first step in destroying the fungus life. In fact, this is what is partially accomplished when timber is seasoned. The timber is piled so as to permit free circulation of air around each piece, and, in this manner, the moisture content can be reduced from 15 to 18 percent. Kiln drying will still further reduce the moisture content, but timber, whether air dried or kiln dried, will reabsorb moisture when exposed to it. A more effective method of timber preservation is to treat the timber with some preservative which will change the organic matter in the inner structure so as to no longer serve as food for the fungi. The use of a preservative treatment will not only preserve the wood from decay but will also fill the pores and prevent the absorption of other fluids, which is a very desirable characteristic for wood blocks, since it tends to eliminate expansion, increases the resistance to wear, and makes the pavement more sanitary.

Preservatives. The preservatives used are copper sulphate, zinc chloride, creosote, and bichloride of mercury. The process of using zinc chloride is also known as burnettizing, and that one in which bichloride is used is known as kyanizing. The use of copper sulphate has been practically given up, and there are only a few places which use the bichloride process, so that, practically speaking, the processes in the United States are restricted to those using creosote and zinc chloride. Of these two the creosoting process is by far the most common, and is the better particularly if the wood is to be used where it will be wet, since the zinc chloride is soluble in water and will leach out of the wood.

Creosote. Creosote may be obtained by the distillation of coal tar, of wood tar, or water-gas tar: Mixtures of coal tar, creosote oils and water-gas tar creosotes, of creosote oils and resin,

and mixtures of creosote oils and coal-tar pitch have been employed. It has been realized for some time that the success of a wood pavement depends largely upon the character and quality of the creosote oil used in treating the blocks. The oil must serve not only to preserve the wood against decay, but also to protect the block so that it will neither expand nor contract, and it must be of such a consistency that it will maintain the qualities in the block for a long period of time. One of the most successful wood pavements that has ever been laid, Tremont Street in Boston, was constructed with blocks impregnated with a mixture of one-half creosote oil and one-half resin. Similar pavements were laid on the streets of lower New York up to 1904. The resin was incorporated in the creosote to hold it in the block. In 1907 the proportion of resin in the creosote was reduced to 25 percent in the New York specifications, and in 1909 it was decided that an oil with a gravity of 1.12 needed no resin at all. The following specifications are quoted from those adopted in 1912 by the Association for Standardizing Paving Specifications:

"Specification A. The preservative to be used shall be a product of coal gas, water gas, or coke-oven tar, which shall be free from adulterations and contain no raw or unfiltered tars, petroleum compounds, or tar products obtained from processes other than those stated.

"The specific gravity shall not be less than 1.10 nor more than 1.14 at a temperature of 38 degrees Centigrade.

"Not more than 3½ percent of the oil shall be insoluble by hot continuous extractions with benzol and chloroform.

"On distillation, which shall be made exactly as described in Bulletin No. 65 of the American Railway Engineering and Maintenance of Way Association, as shown in the appendix to these specifications, the distillate based on water-free oil shall not exceed ½ of 1 percent up to 150 degrees Centigrade, and shall not be less than 30 or more than 40 percent up to 315 degrees Centigrade.

"The oil shall contain not more than 3 percent of water.

"The manufacturer of the blocks shall permit full and com-

plete sampling at all times and places, and shall, if required, furnish satisfactory proof of the origin of the preservative.

"Samples of the preservative, taken from the treating tank during treatment, shall at no time show an accumulation of more than 2 percent of sawdust, dirt, or other foreign matter. Due allowance shall be made for such accumulation of foreign matter by injecting an additional quantity of oil into the blocks."

"Specification B. The preservative to be used shall be a distillate of coal-gas or coke-oven tar, and shall be free from all adulteration and contain no raw tar, filtered or unfiltered tars, or pitches, petroleum compounds, or other tar products.

"It shall be completely liquid at 38 degrees Centigrade, and shall have a specific gravity at that temperature of not less than 1.03, nor more than 1.08.

"It shall contain not more than 2 percent of matter insoluble by hot extraction with benzol and chloroform.

"On distillation, which shall be made exactly as described in Bulletin No. 65 of the American Railway Engineering and Maintenance of Way Association, as shown in the appendix to these specifications, the distillate based on water-free oil shall be within the following limits:

At 210	degrees	Centigrade	not	more	than	5	percent.
" 235	"	"	"	"	"	35	"
" 315	"	"	"	"	"	85	"

"The oil shall yield a coke residue not exceeding 3 percent.

"The distillate between 210 degrees Centigrade and 235 degrees Centigrade shall yield solids on cooling to 15 degrees Centigrade. The preservative shall contain not more than 2 percent of water."

The last two clauses of Specification B are the same as those of Specification A.

To show the method of analyzing the creosote oil, the following is quoted from the same specifications:

"In view of the fact that everything depends upon the samples taken for analysis, too much care cannot be used to make sure that such samples are strictly average ones of the whole bulk of the oil. To this end the oil should be completely

liquefied and well mixed before any samples are taken. Wherever possible, a drip sample of not less than 2 gallons should be taken, commencing after the oil has started to run freely. Where this cannot be done, as, for instance, in large storage tanks, samples should be taken from various depths in the tank by means of a tube or bottle, the number of samples depending on local conditions. For taking samples during the process of treatment, it is desirable to take a sample of oil from the storage tank about one foot from the bottom of the tank before the cylinder is filled, and, where possible, a sample directly from the cylinder during the process of treatment. For this purpose a thermometer well is recommended. The sample to be analyzed should be thoroughly liquefied by heating until no crystals adhere to the glass stirring rod, and also well shaken, after which one-half shall be taken for analysis, and the balance reserved as a check test.

"The apparatus for distilling the tar oil or creosote must consist of a stoppered glass retort having a capacity as nearly as can be obtained of 8 ounces up to the bend of the neck when the bottom of the retort and the mouth of the off-take are in the same plane. A nitrogen-filled mercury thermometer of good, standard make, divided into full degrees Centigrade, must be used in connection therewith. The bulb of the retort and at least 2 inches of the neck, must be and remain covered with a shield of heavy asbestos paper during the entire process of distillation, so as to prevent heat radiation, and between the bottom of the retort and the flame of the lamp or burner two sheets of wire gauze, each 20-mesh fine and at least 6 inches square, must be placed. It is also recommended that the flame be protected against the currents. An ordinary tin can, from which a portion of the bottom and all of the top have been removed, placed on a support attached to the burner, has been found to answer the purpose.

"Before beginning the distillation, the retort should be carefully weighed and exactly 100 grams of the oil placed therein. The thermometer should be inserted in the retort with the lower end of the bulb ½ inch from the surface of the oil, and the condensing tube attached to the retort by a tight cork joint. The

distance between the bulb of the thermometer and the end of the condensing tube should not be less than 20 nor more than 24 inches, and during the process of the distillation the thermometer must remain in the position originally placed.

"The distillates should be collected in weighed bottles and all fractions determined by weight. Reports are to be made on the following fractions:

0 to 170	degrees	Centigrade.	
170 to 200	"	"	
200 to 210	"	"	
210 to 235	"	"	
235 to 270	"	"	
270 to 315	"	"	
315	"	"	and above.

"For practical purposes there will be no need of reporting on all of these fractions. It will be sufficient to report on the fractions as follows:

Below 200	degrees	Centigrade.
200 to 210	"	"
210 to 235	"	"
235 to 315	"	"
Above 315	"	"

"Reports are to be made on individual fractions. In making such reports it is to be distinctly understood that these fractions do not necessarily refer to individual compounds. In other words, the fractions between 210 and 235 degrees will not necessarily be all naphthalene, but will probably contain a number of other compounds. The distillation should be a continuous one, and should take about forty-five minutes. When any measurable quantity of water is present in the oil, the distillation should be stopped, the oil separated from the water and returned to the retort, when the distillation should be recommenced and the previous readings discarded. In obtaining water-free oil, it will be desirable to free about 300 to 600 cubic centimeters of the oil by using a large retort and using 100 grams of the water-free oil for the final distillation. In the final report as to fractions a correction must be made of the amount of water remaining, so that the report may be made on the basis of a dry oil."

The creosote oil used abroad is lighter as a general rule than that recommended for use in this country, the gravity being about 1.07. In Paris and Germany some blocks are immersed in a bath composed of a mixture of coal-gas tar and heavy oil.

Manufacture of Blocks. Planks which have been sawed from the logs and correctly sized are cut up into blocks by a machine specially designed for this purpose. The machine consists of a series of circular saws spaced at a distance apart depending upon the size of the block to be cut. The bed of the machine is wide enough to take a long plank which is cut into blocks by its passage over the saws. Figs. 164 and 165 show views of the municipal wood block plant in Paris. Some plants have a capacity as high as 240,000 blocks per day.

Size of Blocks. Care must be taken to cut the blocks to the right size. The specifications in regard to this point, adopted in 1912 by the Association for Standardizing Paving Specifications, are as follows:

"The blocks shall be from 5 to 10 inches long, but shall average 8 inches; they shall be 3½ to 4 inches in width; and they shall be 4 inches in depth. The blocks used in any one street or improvement, however, shall be of uniform width, and there shall be always a difference between the width and depth of the blocks of not less than ¼ inch. A variation of 1/16 of an inch shall be allowed in the depth, and ⅛ of an inch in the width of the blocks from that specified. The depth of the blocks may be reduced to 3½ inches in medium-traffic streets and to 3 inches on light-traffic streets or alleys. The width and depth of the blocks, however, must never be equal. In case blocks 3 inches in depth are used, they shall never exceed 8 inches in length."

The size of the blocks used in Europe varies from 2¾ to 4 inches in width, from 7⅛ to 11¾ in length, and from 4¾ to 7⅛ in height. The size used in Paris is approximately 3 inches wide by 9 inches long by 6 inches deep.

Treating the Blocks. There are two methods in use for impregnating the blocks with the preservative fluid: the pressure process and the open-tank process.

Pressure Process. In the pressure process, which is used

almost altogether in treating wood blocks in the United States, the blocks are placed in large iron cylinders which are capable of

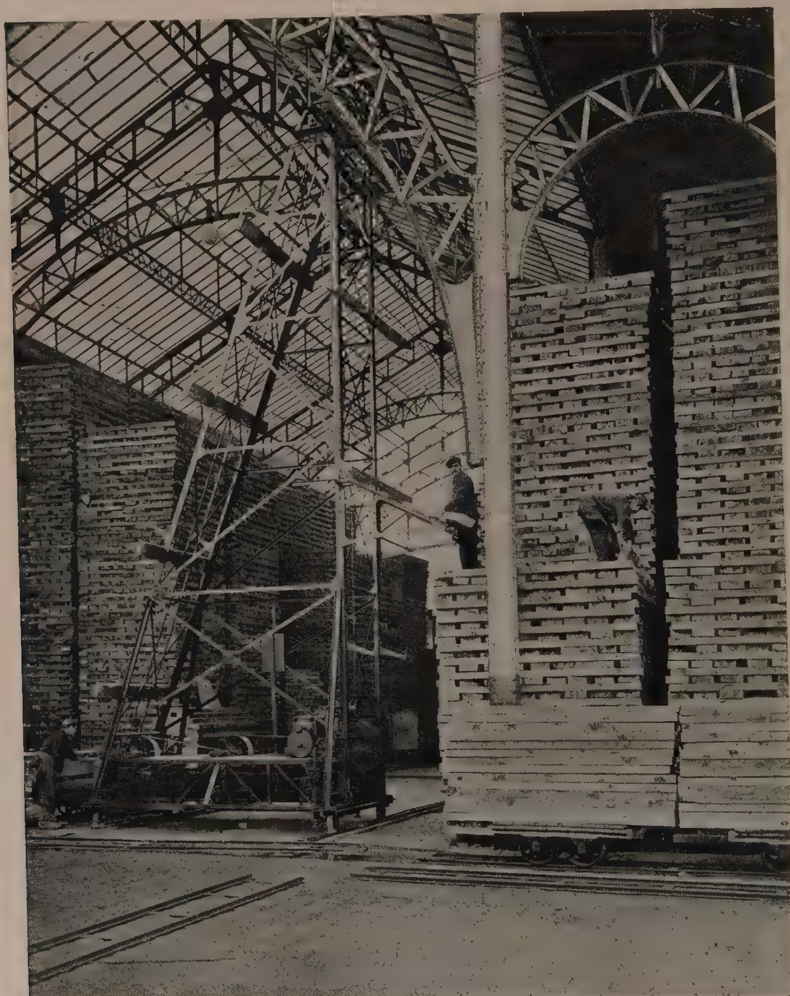

FIG. 164. Storage Piles at Municipal Wood Block Plant, Paris, France.

withstanding pressure. A low steam pressure is maintained for a time which softens the sap. The steam, together with whatever matter it has dissolved out of the wood, is blown out

of the cylinder and a vacuum is established which serves to draw out more of the sap which has been softened by the steam.

FIG. 165. Saws at Municipal Wood Block Plant, Paris, France.

When this step has been completed the preservative fluid is admitted to the cylinder and steam pressure is again applied, so as to force the preservative into the blocks. The pressure

varies, depending upon the kind of wood, nature of the preservative, and the amount it is desired that the blocks will absorb. The amounts of preservative used vary from 16 to 22 pounds per cubic foot of wood. It has been found that it takes on the average about 26 pounds of oil per cubic foot to make a block absolutely waterproof. For this reason blocks which are treated with a less amount should be put into place as quickly as possible, so that they will have no chance to dry out. On streets of heavy traffic a 20-pound treatment is probably not too much. On streets with a light traffic blocks treated with an amount as large as this are liable to bleed. An amount as low as 10 pounds has been commonly used abroad in this process.

The 1912 specifications of the Association for Standardizing Paving Specifications require that:

"The blocks shall be treated with the preservative under pressure and shall at no time be subjected to a temperature of over 240 degrees Fahrenheit. They shall, after treatment, show satisfactory penetration of the preservative, and all blocks that have been warped, checked, or otherwise injured in the process of treatment shall be rejected. The blocks shall be treated with the preservative so that the pine and tamarack blocks shall contain not less than 18 pounds, and the gum blocks not less than 22 pounds per cubic foot. This amount in pine and tamarack blocks may range from 16 to 20 pounds at the discretion of the engineer, dependent on local conditions."

Open-Tank Process. In the open-tank process, the blocks are placed in a tank which is filled with hot preservative and left for a period of time which varies from a few minutes to an hour, depending upon the kind of wood and the depth of impregnation desired. The tank is then drained off and the blocks are allowed to drip. This method is used to a large extent in France.

Testing the Blocks. The French practice is to conduct careful tests for resistance to wear when saturated with water, resistance to compression and impact, and to determine the amount of water the treated wood will absorb. In this country the most common tests are the amount of clear water absorbed in a certain length of time and the analysis of the preservative

fluid to see whether the specifications have been complied with.

Water Absorption. The specifications of the Borough of the Bronx, New York, one of the few that demand this test, require that, "After treatment the blocks shall show such waterproof qualities that after being dried in an oven at a temperature of 100 degrees Fahrenheit, for a period of 24 hours, weighed and then immersed in clear water for a period of 24 hours, and again weighed, the gain in weight shall be not more than 3½ percent for pine and tamarack and not more than 4½ percent for gum." Tests have shown that blocks will absorb sometimes as much as 100 percent more water a few weeks after treatment than they will within a few hours after creosoting. Hence the blocks should be tested on the site of the work rather than at the plant if the amount of water absorbed is believed to be of importance. Ten or twelve blocks taken from the piles along the street constitute a sample for this test.

Amount of Preservative Fluid. In order to make sure that the preservative treatment has thoroughly impregnated the wood, several blocks in each charge may be split open and examined. If it is evident that the oil has not thoroughly penetrated the block, the blocks are re-treated. Quoting from the 1912 specifications of the Association for Standardizing Paving Specifications: "The following method is recommended for testing blocks taken from the street. The blocks shall be tested for amount of preservative contained by boring a hole ¾ of an inch in diameter through the block parallel to the fiber at a point half-way on the longest line that can be drawn from the center of the heart to the edge of the block. If the center of the heart does not occur in the block, the hole shall be bored in the center. The borings shall be mixed and an average sample taken." The test for the creosote oil has been previously stated.

Construction

Subgrade and Foundation. The roadbed is excavated to the required grade. It is assumed that all subdrains, catch-basins, inlets, curbs, etc., have been constructed. The subgrade

is shaped to the surface of the finished pavement and is carefully rolled and compacted. Fig. 166 shows a cross-section of a wood block pavement as constructed in Pittsburg, Pa. Any poor material which does not compact properly should be removed and replaced with material of good quality.

On the subgrade is constructed the concrete foundation, built generally by the mixing method as described in Chapter VI. The thickness of the foundation varies from 4 to 8 inches, depending principally upon the traffic, an average value being 6 inches. A thickness of 9 inches has been recommended in England for streets subjected to the traffic of heavy motor omnibuses. Portland cement concrete is almost universally specified. The concrete foundation, like the subgrade, is built parallel to the

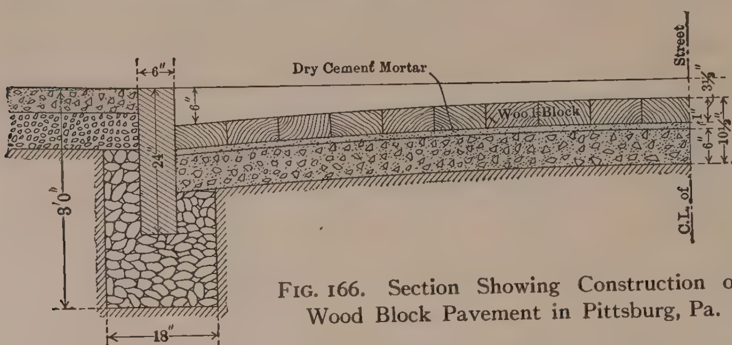

FIG. 166. Section Showing Construction of Wood Block Pavement in Pittsburg, Pa.

finished surface of the pavement. The amount of crown to be used can be determined from the formulas given in Chapter IV. It is important for the surface of the concrete to be finished evenly if a smooth surface in the finished pavement is expected. This can readily be done, if the stones are depressed and the mortar brought to the surface, by striking off the surface of the foundation with a wooden template before the concrete sets up. During the time that the concrete is setting it should be kept wet, particularly in hot weather, and in cold weather should be protected from freezing.

Cushion Layer. The French practice is to place a thin layer of mortar on the surface of the concrete foundation before it sets up and to make this surface so regular and smooth that

the wood blocks can be laid directly upon it without any intermediate layer of material. The layer of mortar becomes, in fact, a part of the foundation. The practice in America, however, is to place either a layer of sand or mortar on the concrete foundation after the latter has set up. The cushion is made from ½ to 1 inch in thickness. The object of either kind of cushion is to provide an even surface in the finished pavement. The mortar cushion is also used to waterproof the bottom of the blocks. One objection to the mortar cushion as used in the United States is that it takes some time for it to set up and precludes the use of the pavement until this condition has been obtained. On the other hand, a sand cushion may give some trouble if the pavement is constructed with open joints, since there is a possibility of water leaching down through the joints to the sand and displacing the latter. Furthermore, a sand cushion does not so effectively waterproof the bottom of the blocks.

Specifications. The specifications for the cushion layer adopted in 1912 by the Association for Standardizing Paving Specifications are as follows:

"Sand cushion. The blocks shall be laid on a cushion of clean, coarse sand, 1 inch in thickness, which shall be struck to a surface parallel with the grade and contour of the finished pavement.

"Mortar cushion. Before placing the cushion the surface of the concrete shall be cleaned and thoroughly dampened. A layer of sand and cement not to exceed 1 inch in thickness, mixed dry in the proportion of one part of Portland cement to four parts of sand, shall be spread upon the concrete foundation and struck to a surface parallel to the grade and contour of the finished pavement. This cushion of sand and cement, unless previously moistened, shall be lightly sprinkled with water, and the blocks shall be immediately set thereon. Under special conditions, particularly where vibration may be expected, the sand or mortar cushion may be omitted and a bituminous coating, spread upon a smoothly finished and thoroughly dry concrete base, substituted therefor."

The 1912 specifications of the American Society for Municipal Improvements do not differ materially from those just quoted except in the following respects: The sand for the sand cushion must all pass a ¼-inch screen. In laying the mortar cushion the mortar is mixed with water before being placed on the foundation, and only sufficient water is added to insure a proper setting of the cement, the intention being to produce a granular mixture which may be raked to the desired grade.

Laying the Blocks. One method of laying the blocks is well described by the 1912 specification of the American Society for Municipal Improvements.

"Upon the bed thus prepared the blocks shall be carefully set with the fiber of the wood vertical in straight parallel courses at right angles to the curb, except that one row of block shall be placed parallel with the curb and ¾ of an inch therefrom. The space thus formed between the curb and this row of blocks shall be filled with a bituminous filler having a penetration between 30 and 40 when tested at 77 degrees Fahrenheit. On streets 50 feet or more in width, a second row of blocks parallel to the first row along the curb and ¾ of an inch therefrom, shall be laid and the space between the two rows filled with a bituminous filler as above, thus forming a double expansion joint. When deemed advisable by the engineer on streets for heavy traffic, the row or rows of blocks parallel with the curb and the expansion joint may be dispensed with.

"The blocks shall be laid by setting them loosely together on the cushion coat, but no joint shall be more than ⅛ of an inch in width. Nothing but whole blocks shall be used, except in starting a course or in such other cases as the city may direct, and in no case shall less than one-third of a block be used in breaking joints. Closures shall be carefully cut and trimmed by experienced men. The portions of the blocks used for closure must be free from check or other fracture, and the cut end must have a surface perpendicular to the top of the block and cut to the proper angle to give a close, tight joint.

"After the blocks are placed, they shall be rolled by a steam roller until the surface becomes smooth and is brought truly to

the grade and contour of the finished pavement. When laid on a mortar bed, the rolling shall be completed before the mortar has set, and all mortar that has set before the blocks are in place and rolled shall be discarded and replaced by fresh mortar."

The success of the wood block pavements in Minneapolis is supposed to be due in part to the fact that the blocks are laid as soon as possible after they are received on the street and are then kept wet by sprinkling.

In the Middle West a large amount of wood block pavement is constructed by laying the blocks parallel to lines that make either an angle of 45 or 67½ degrees to the curb rather than on lines at 90 degrees to the curb line, as is the practice in the East. The engineers who advocate laying the blocks on angular lines believe that the pavement is benefited because the joints are not so severely exposed to blows of horses' hoofs. Moreover, they claim that with this type of construction no transverse expansion joints are necessary, all expansion being taken up by the longitudinal joints at the curb. These claims, however, do not seem to have been sufficiently well substantiated to warrant the general adoption of this method of laying the blocks, and also it is a more troublesome and expensive pavement to lay, since skew blocks must be cut to fit the curbs at either end of each row of blocks. When the blocks are laid on lines making 90 degrees with the curb lines specifications frequently require transverse expansion joints to be left 1 inch wide every 50 or 100 feet along the street.

The practice in Europe is to dip the bottoms of the treated blocks in hot tar or asphalt and lay them directly upon the surface of the concrete foundation, which has been given a perfectly smooth and even surface. Sometimes the foundation is mopped with bituminous material and the blocks are laid directly upon it without being dipped. By means of strips of wood a space ⅛ to ⅜ of an inch wide is left between the rows of blocks. The joints are filled with hot pitch, which is brushed out as soon as it is applied, so that the joints remain only half full. Clean gravel, from ⅛ to ⅜ of an inch in size, is spread on and broomed into the joints so as to fill the upper half and enough is left on

the surface to take up the excess of bituminous material. In some instances the blocks are laid close together and the surface is coated with a thin layer of tar or tar-asphalt on which is spread a layer of sharp sand or gravel. This is rolled in and forms a durable coating that protects the blocks. Sand and gravel are frequently applied to the surface during the life of the pavement.

It is the practice in St. Louis to omit both the sand and the mortar cushion. The concrete foundation, which has been prepared with an extremely smooth and regular surface, is given a coat of hot bituminous material directly before placing the blocks upon it. Each block as it is set into place is dipped on one side and one end in the same bituminous material that is used to cover the foundation. The side and end of the block that is dipped are placed against the adjacent side and end of blocks previously laid which were not dipped. By this method the foundation is waterproofed as well as the underside of the blocks, while the troubles arising from expansion are reduced. The cost of laying blocks by this method is more than where either the sand or mortar cushion is used.

Filling the Joints. After the blocks have been thoroughly rolled, the joints are filled with a find sand, a cement grout, or some form of bituminous material.

Sand Filler. According to George W. Tillson, M. Am. Soc. C. E.,* "The first joint filler in modern wooden pavements was sand. Afterward Portland cement grout and bituminous fillers were used. The speaker has always used sand. Wood blocks are so regular in form that they lie closely together in the pavement and need a filler only to keep them in place. It may be said that with a sand filler the pavement will not be waterproof, but experience seems to demonstrate that the blocks, under traffic, soon mat together, making a surface which is practically continuous. The speaker recently examined a pavement of this character which had been subjected to light traffic for some 7 or 8 years, during which time it had been perfectly satisfactory. The sand should be fine, and thoroughly dry when applied, so

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* See Trans. Am. Soc. C. E., Vol. LXXV, pages 530–532.

that the joints will be entirely filled. Should oil at any time exude from the blocks, the sand will assist in absorbing it."

Grout Filler. "Where a cement grout is used, it is made of equal parts of fine sand and the best Portland cement, carefully mixed, and swept into the joints until they are completely filled. The pavement is then covered with sand, and the grout should be allowed to set for at least seven days before the pavement is used. If the blocks are disturbed before the grout has set, the filling becomes of no more value than sand, and, as far as its absorptive properties are concerned, is even of less value."

Bituminous Filler. "Coal-tar pitch, asphalt, and special bituminous fillers are also used quite extensively by different cities, the idea being to make the pavement waterproof as well as to provide for some slight expansion of the blocks. Where such fillers have been used and excessive bleeding has occurred, much of it has been attributed to the bituminous filler."

Specifications for Filler. "There seems to be considerable difference in the practice of cities regarding the joint filler for wood pavements. For instance, the specifications of St. Louis, the Boroughs of Manhattan and Brooklyn, New York City, and those adopted by the American Society for Municipal Improvements call for sand; those of Detroit, for sand or paving cement obtained from the direct distillation of coal-tar, or any other approved composition; those of Indianapolis, for an asphalt filler prepared from such asphalt and flux, if the latter is needed, as will conform to the specifications for asphalt paving cement; it must not be brittle at 32 degrees Fahrenheit, nor flow at 120 degrees Fahrenheit; it must adhere firmly to the blocks, and be sufficiently pliable to permit expansion and contraction; and those of Newark require a filler made of one part Portland cement and two parts sand. The specifications of Westminster, England, require the following: 'All pavements shall be laid so as to have as little space as possible at the sides and ends of the blocks, and, on completion, a mixture of boiling pitch and creosote oil, in approved proportions, shall be poured over the whole surface, be well forced into the joints, and be scraped off with wooden

or rubber squeegees, the joints being thoroughly filled. The pavement shall then be finished with fine sand and cement grout in equal proportions, brushed over, and have a top dressing of approved gravel which will pass a ½-inch mesh, and be free from sand.'"

Examples of Construction and Cost Data. In 1910 several large contracts were let for wood block paving in Chicago, Ill. The pavements were constructed with an 8-inch Portland cement concrete foundation with a 1 : 3 : 6 mixture. A sand cushion from ½ to 1 inch thick was placed on the concrete foundation. The blocks were of long-leaf yellow pine treated with 16 pounds to the cubic foot of creosote oil which was a pure coal-tar product. The blocks were laid at an angle of 45 degrees to the center line of the street, with the exception of a strip of 18 inches wide along the car tracks and of the same width next to the curbs where a tar filler was used. The joints were filled with a coarse sand. The prices for this work varied from $3.16 to $3.45 per square yard.

TABLE No. 23.

From *Engineering and Contracting*, April 3, 1912.

City	Square Yards	Cost per Sq. Yd.	Foundation		Kind of Filler
			Kind	Thickness	
Boston, Mass.	14,652	$3.25	Concrete	6	Grout
Springfield, Mass.	6,722	3.09	"	5	Sand
Bridgeport, Conn.	52,050	3.11	"	6	Sand
Chester, Pa.	36,730	2.74	"	6	Grout
Wausau, Wis.	10,660	2.53	"	6	Pitch
Minneapolis, Minn.	172,949	2.70	"	5	Pitch
Kansas City, Mo.	20,000	3.05	"	6	Sand
St. Louis, Mo.	45,297	2.60*	"	6	Sand
Americus, Ga.	36,000	2.21*	"	4	Sand
Wichita Falls, Tex.	40,000	2.55*	"	5	Sand
Spokane, Wash.	4,332	2.90	"	5	Asphalt
Portland, Ore.	4,397	2.93*	"	6	Asphalt

* Does not include grading.

In Atlanta, Ga., the pavements are laid on a 1 : 4 : 8 Portland cement concrete base. The blocks are laid upon a ½-inch sand cushion. Long-leaf yellow pine blocks treated with 20 pounds of preservative, either a dead oil of coal tar or coal-tar product, are used. The blocks are laid at right angles to the curbs. Three rows of blocks adjacent to the curb are laid parallel to the latter and the joints are filled with a coal-tar paving pitch. The joint filler used in other parts of the pavement is sand. In 1910 the cost of constructing several different streets varied from $2.45 to $2.68 per square yard.

Table No. 23 shows the cost of wood block paving in 1911 in several other American cities.

The cost* of constructing 145,000 square yards of wood block pavement in Minneapolis in 1908 was as follows:

	Per sq. yd.
Removing old cedar paving	$0.0270
Grading	.1320
Concrete base (labor and materials)	.5226
Cushion sand, at $0.60 per cu. yd	.0200
Creosoted paving blocks f. o. b. Minneapolis	1.3900
Hauling blocks	.0450
Laying blocks	.0590
Hauling cement	.0090
Paving pitch filler, at 5.7 cents per gal	.0570
Hauling pitch for filler	.0100
Labor on filler	.0120
Asphalt filler along street railroad tracks	.0029
Headers (plant)	.0030
Sand on finished paving	.0100
Tools	.0200
Rolling	.0100
Cleaning up finished street	.0050
Miscellaneous materials	.0030
Miscellaneous labor	.0100
	$2.3475

The organization and wages of the gang directly engaged in laying the blocks were about as follows:

* See Gillette's "Cost Data," p. 384.

	Per Day
6 pavers at $2.50	$15.00
6 helpers setting up blocks, at $2.00	12.00
7 wheelers, at $2.00	14.00
4 sand cushion men and sweepers, at $2.00	8.00
2 sand cushion men and sweepers, at $2.25	4.50
2 sand cushion men and sweepers, at $2.50	5.00
1 grader, at $2.25	2.25
1 water boy, at $1.20	1.20
Total 1,050 square yards	$61.95

The Ninth Annual Report of the Metropolitan Paving Committee of London contains several descriptions of construction of wood block paving in and around London. The cost of laying 8 by 3 by 4 inch creosoted deal blocks in Hampstead on a 6-inch Portland cement concrete foundation with a pitch filler was $1.87 per square yard. In Kensington, creosoted deal blocks of about the same size were laid on a 6-inch Portland cement concrete foundation and grouted with tar pitch and cement at a cost of $3.10 per square yard. In the City of London, creosoted deal blocks on an 8-inch Portland cement concrete foundation, the joints being filled with a mixture of pitch and oil, cost from $2.83 to $3.25 per square yard. In the City of Westminster, creosoted pine blocks laid on a 6-inch Portland cement concrete foundation, the joints being poured first with a mixture of boiling pitch and creosoted oil and afterwards with cement grout, the surface being top dressed with ⅜-inch chips, cost from $2.85 to $3.10 per square yard.

The cost of wood pavements in Paris is variable, depending upon the size of block used and the kind of wood. The following table gives the range of costs:

Pine of Landes	from	$2.40	to	$3.00	per	square	yard
Pine of Nord	"	2.40	to	3.00	"	"	"
Pitch pine	"	2.60	to	3.60	"	"	"
Jarrah or Karri	"	3.60	to	5.20	"	"	"
Lime	"	3.20	to	4.60	"	"	"

Maintenance

Bleeding of Pavements. One of the principal troubles with wood block pavements is the oozing out of the preservative fluid, particularly during the warm weather. See Fig. 167. The cause of this bleeding is attributed to the character and quality of the preservative fluid used, the expansive effect of heat on the blocks, and the use of too much preservative fluid per cubic foot. In some cases where a bituminous filler has been

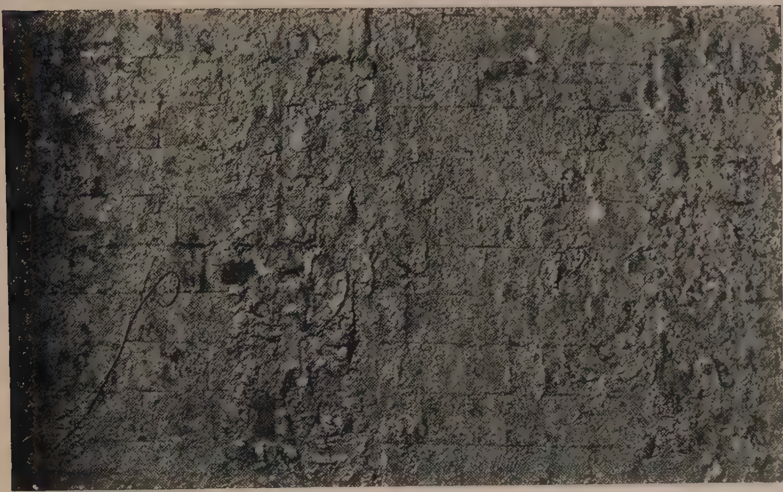

Fig. 167. Bleeding on the Surface of a Wood Block Pavement.

used and this condition has prevailed, the bituminous filler has been blamed. The pavement while in this condition is extremely objectionable, but it may later prove to be satisfactory after the bleeding ceases. In Norfolk, Va., where the oil oozed from the surface of wood block pavements, dry sand was applied and, when it became thoroughly saturated, was scraped off and a second application of sand was made. Sawdust was tried as a substitute for sand, but was not found to be effective. The pavements referred to in Norfolk were treated with 25 pounds of preservative per cubic foot. The wood pavement on Market Street in Philadelphia acted in a similar manner. The blocks

were treated with 24 pounds of oil per cubic foot. At the present time, however, the pavements in both of these cities are in excellent condition. If the blocks are properly treated, pavements do not generally ooze much longer than the first few months of hot weather, although there are some instances where pavements have oozed for four or more years. In these cases the oil seems to run out, not only during the hot weather, but also during the early spring and late fall.

Repairs to Surface. The other maintenance work required consists of removing any poor blocks and of raising low spots and lowering the pavement in places which have bulged up. Places which have bulged up can generally be attributed to the lack of adequate expansion joints. This fault is accentuated if the blocks absorb water to any great extent.

Prevention Against Slipperiness. During wet and frosty weather it will be frequently necessary to spread a light coating of sand over the pavement in order to prevent it from becoming unduly slippery. In France and England the experiment is being tried of coating the wood pavements with a bituminous surface.

Relaying. The life of some of the wood pavements in Paris has been prolonged by taking up blocks after several years of service and sending them to the municipal plant, where the tops are sawed off so that the blocks are again of uniform depth, and then relaying these blocks with the original bottom surface as the wearing surface.

Cost of Maintenance. The wear of wood block pavements is very remarkable. A block taken from a street in Chicago, which had been down for six years and subjected to the traffic of many 6- and 8-ton loads, was found to measure 3.9 inches on the one end and 3.85 inches on the other, its original depth being 4 inches. There are wood pavements in Chicago which are ten years old and apparently good for another ten years.

There are two wood-paved streets in St. Louis which were laid in 1903 that, in 1910, were in excellent condition, the total repair charges on the 60,000 square yards of pavement for the seven years being only $2.10. The streets, while not receiving the

heaviest traffic, are subjected to considerable hauling in the form of ice, coal, and building material wagons.

Tremont Street in Boston, which carries a heavy traffic, was constructed partly of wood block pavement in 1900. One-half of the street was surfaced with wood blocks and the other half with sheet asphalt. In 1909, Dow and Smith, Consulting Paving Engineers, made a report on this street and said in part: "A straight-edge laid upon the wood blocks where they join the asphalt shows a difference in level of approximately ¾ of an inch, proving that the asphalt has worn down that much. This difference added to the average thickness of the remaining asphalt pavement would show that the wear on the blocks has been practically nil. The condition of the blocks themselves confirms this, as even where the pavement is practically grooved by separating the blocks, the tops of the blocks show no brooming whatever. To all appearances these blocks, although subjected to a severe traffic for the past nine years, are practically as good as the day they were first put down. There has been no maintenance cost whatever."

In 1906 an experimental wood block pavement was laid with the cooperation of the government, the city engineering department, and several wood block paving companies in Minneapolis, Minn. The woods used were long-leaf pine, Norway pine, tamarack, Douglas fir, hemlock, western larch, and white birch. Table No. 24* gives the results of the wear on blocks in the different sections when inspected in 1910.

James P. Norrington, in an article entitled "Wood Paving," states that the life of untreated deal blocks in England is about five to six years, whereas when creosoted the average life is about fourteen years. Blocks of jarrah lasted from ten to twelve years. The traffic to which some of these streets are subjected is as much as 9,000 vehicles in 12 hours.

In Paris, on the streets which are subjected to as many as 65,000 teams per day, or 3,400 per square yard of width, the wear is, on the average, 0.4 of an inch per year. The average life of

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* See Forest Service Circular No. 194, U. S. Department of Agriculture.

TABLE No. 24.

RESULTS OF INSPECTION OF EXPERIMENTAL PAVEMENT LAID IN MINNEAPOLIS, MINN., IN 1906.

Section No.	Species	Area of section.	Original depth of block.	Depth of block of average wear for section.[1]	Average wear of section.[1]	Area local depression one-half inch and less below general level of section.	Area local depression one-half inch and less below general level of section in percent of total area of section.	Area local depression 3 inches to one-half inch below general level of section in percent of total area of section.	Remarks
		Sq. Ft.	Inches	Inches	Inches	Sq. Ft.	Percent	Percent	
1	Norway Pine........	440	$3\frac{15}{16}$	$3\frac{3}{4}$	$\frac{3}{16}$	10	2.0	.....	All apparent depressions in one spot, possibly due to fire.
2	Tamarack...........	742	$3\frac{15}{16}$	$3\frac{3}{4}$	$\frac{3}{16}$	10	1.0	.....	....
3	White birch (6 and 8-inch blocks)........	1609	$3\frac{13}{16}$	$3\frac{5}{8}$	$\frac{3}{16}$	8	.5	.....	About 40 to 50 blocks removed on account of decayed heart.
4	White birch (4-inch blocks)............	1615	$3\frac{13}{16}$	$3\frac{5}{8}$	$\frac{3}{16}$	10	.5	.....	Some blocks showed decayed heart.
5	Western larch (4-inch blocks)............	1505	$3\frac{13}{16}$	$3\frac{1}{2}$	$\frac{5}{16}$	33	2.0	.....	....
6	Western larch (6 and 8-inch blocks)........	1497	$3\frac{13}{16}$	$3\frac{7}{16}$	$\frac{3}{8}$	55	3.5	.....	....
7	Douglas fir..........	1229	$3\frac{15}{16}$	$2\frac{7}{8}$	$1\frac{1}{16}$	.....	30.0	35.0	Medium grain, 6 to 7 rings per inch.
8	Douglas fir..........	1293	$3\frac{15}{16}$	$2\frac{7}{8}$	$1\frac{1}{16}$	.....	30.0	3.0	Coarse grain, 3 to 5 rings per inch.
9	Long-leaf pine........	3583	$3\frac{15}{16}$	$3\frac{7}{8}$	$\frac{1}{8}$	17	.5	.....	....
10	Eastern hemlock.....	3038	$3\frac{15}{16}$	$3\frac{3}{4}$	$\frac{3}{16}$	35	1.0	.....	....

[1] Exclusive of local depressions below the general level of the section.

pine paving blocks in Paris that have not been treated under pressure is about eight years. Some wood blocks which have been creosoted under pressure and used in Paris have been down for fifteen years and are still in good condition.

Characteristics

A wood block pavement built with blocks that have been treated with a preservative and properly constructed makes an excellent pavement which stands up under heavy traffic in a remarkable manner. This fact has been substantiated in many places, not only in this country, but also in France and England. It is much less noisy than a stone block, brick, or an asphalt pavement, and from the standpoint of the tenants of buildings along the street, this feature of a wood block pavement is distinctly appreciated. From the standpoint of teamsters, however, there is an objection to wood block pavement on account of its slipperiness. It is only fair to state that this condition is noticed principally at times when the pavement is in a slightly moist condition, but under the same conditions it is probably not much more slippery than an asphalt pavement. When too much preservative fluid has been used in treating the blocks and a bituminous filler has been used in between the joints, there is very liable to be some inconvenience and unpleasantness experienced by the exuding of these materials on the surface. That the pavement is durable cannot be denied. If properly constructed it presents an extremely smooth surface, which is readily cleaned.

CHAPTER XVII

STONE BLOCK PAVEMENTS

Development. Stone block pavement is the oldest known form of permanent pavement. The historical review of the types used prior to about A.D. 1840 has already been treated in Chapter I. As stated in that chapter, Telford, in 1824, was apparently the first to recognize the importance of the smaller size blocks cut in such a manner as to give close joints and the value of a stable foundation. London further developed this type of pavement, mortar joints being first used in 1840, while later, about 1872, a method of construction, using both a concrete foundation and tar and gravel joints, was adopted.

Belgian blocks, so-called because they were first used in Belgium, were similar to a truncated pyramid in shape, having a base of 5 to 6 inches square, a depth of from 7 to 8 inches, the other face having dimensions not more than 1 inch smaller than those of the base. This type of pavement was commonly found in European cities, while in 1859 it became quite common in New York. It was impossible to maintain a smooth surface with these irregular shaped blocks, and ultimately it led to the adoption of the rectangular block pavement. This shape of block was first used in New York City about 1876. Due to the fact that the first Belgian block pavements laid in New York were constructed with blocks of trap rock taken from the Palisades on the Hudson, any trap rock block pavement was called Belgian block regardless of the shape of the block.

In the more recent development of the rectangular stone block pavement more attention has been paid to the accurate cutting and sizing of the blocks, the joint filler, and the foundation. The blocks are generally required to be laid on a concrete foundation and sand, tar and gravel, asphalt and gravel, and cement grout are used as fillers. Within the past few years the use of small block pavements has become more or less extensive

in certain parts of Europe. Both 4-inch cubes and smaller setts, approximating 2¾-inch cubes, have been employed in this construction.

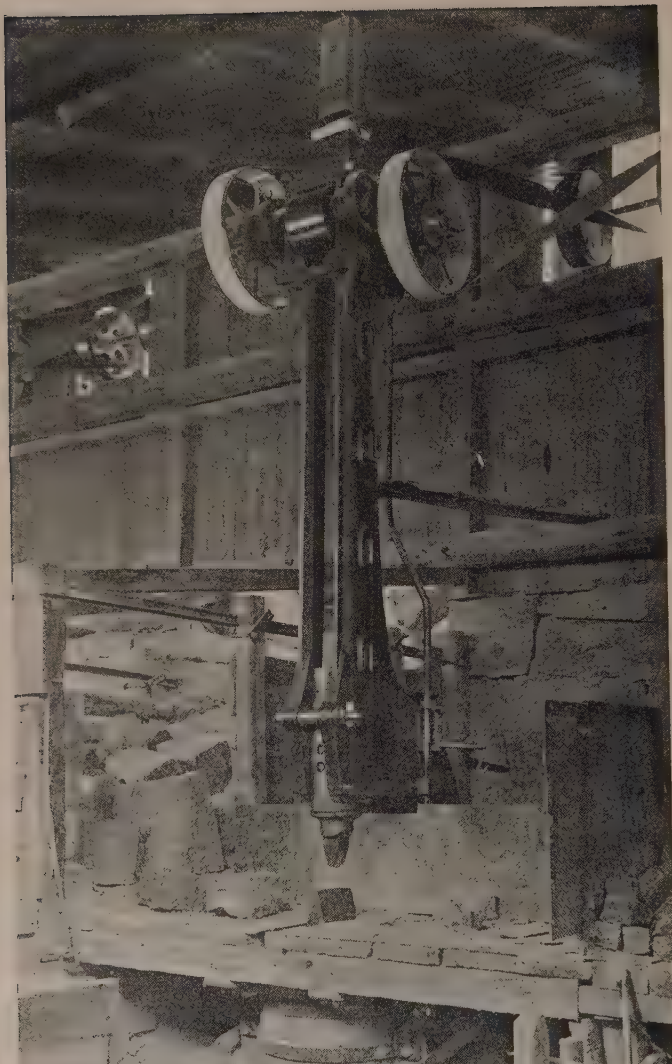
Stone Blocks

The Stone. The blocks are generally made of granite. Sandstone, quartzite, and trap rock are also employed. The stone should be of such quality that it will resist weathering and will not wear round and smooth under the action of traffic.

The planes of cleavage of granite are such that it is easy to make blocks from it. The trap rocks are harder and tougher than the granites and are not so easily made into blocks. Sandstone blocks are not usually suitable for streets taking an extremely heavy traffic. They do not wear round like the granite blocks, but more uniformly, although sometimes very rapidly. Sandstone cuts into blocks readily. The Medina and Potsdam sandstones which are found in New York State have been used to a considerable extent throughout this State in pavements. In Rochester, N. Y., dressed Medina stone is used with excellent results on the main streets taking a heavy traffic. A large amount of quartzite has been laid in Chicago with good results.

Manufacture of the Blocks. The majority of stone blocks are made by hand tools. Large blocks of stone are split up into sizes desired by the use of plugs and feathers. The faces of the small pieces are then hammer-dressed until smooth enough to comply with the specifications. The small-sized blocks used in the construction of Kleinpflaster and Durax pavements are cut out by a machine, which is illustrated in Fig. 168.

Considerable care has to be taken in making blocks for a first-class pavement. The blocks should be dressed so as to be rectangular on the faces, having parallel sides and ends with right angle corners. Some specifications do not allow depressions on the face exceeding ¼ of an inch. If the faces are not all free



Courtesy of the Wern Machinery and Engineering Company.

FIG. 168. Machine for Cutting Durax and Kleinpflaster Blocks.

from bulges and hollows, it is impossible to get close and even joints in the pavement.

Size of Blocks. The size of blocks is quite variable. In the United States large standard blocks for a first-class pavement are from 7 to 8 inches deep, 3 to 4½ inches wide, and from 8 to 12 inches long. A light block is also used under certain conditions which is from 4 to 4½ inches deep, 3½ to 4 inches wide, and 6 to 12 inches long.

In Liverpool, England, blocks for heavy-traffic streets are 6 inches deep, 3 inches wide, and 5 to 6 inches long. In Birmingham, England, blocks which are approximately 4-inch cubes are used. This same size block has also been adopted in Belfast, Ireland, but it is generally made 6 rather than 4 inches in depth.

The stone blocks used in France are either cubical or rectangular in shape and of very variable dimensions, the lengths varying from 6 to 9 inches, the width from 4 to 8 inches, and the depth from 6 to 9 inches.

In Hungary the stone blocks are somewhat larger than are commonly used in other European countries. The largest blocks are 7-inch cubes; a three-quarter size block, so-called, measures 7 by 7 inches on the face and is 5 inches deep; the conical shape blocks are 7 inches square on the top face and have a bottom face two-thirds the area of the top; the smallest size blocks are 3- to 4-inch cubes.

The blocks for Kleinpflaster and Durax pavements are somewhat similar in size. Those for Kleinpflaster are roughly 2¼ by 2¼ by 2¾ inches in size. The blocks for the Durax pavement are from 2¾ to 3½ inches in size.

Tests for Block. There are no standard tests for stone block which have been adopted in the United States. The qualities of the stone of which a block is composed, however, can be determined by submitting it to the abrasion, hardness, and toughness tests as made in connection with the tests of broken stone. These tests have been previously described in Chapter IX. The crushing strength of the stone is the only characteristic that is determined by some engineers.

Specification. The following specification which is quoted

from those adopted in 1912 by the Association for Standardizing Paving Specifications will serve to show what are considered to be the requirements for stone blocks suitable for use in a first-class pavement:

"The paving blocks, which shall be of medium grained granite, showing an even distribution of constituent material, shall be of uniform quality and texture, without seams, scales, or discolorations showing disintegration, free from an excess of mica or feldspar, and equal in every respect to the sample in the office of the engineer.

"The granite shall preferably be such as will give above 16,000 pounds per square inch crushing strength, combined with a uniform structure and toughness. The toughness to be determined by the method employed by the Department of Agriculture of the U. S. Government.

"Blocks shall be of the following dimensions, viz., not less than 8 inches nor more than 12 inches long on top, not less than 3½ inches nor more than 4½ inches wide on top, not less than 5 inches nor more than 5½ inches deep.

"The blocks shall be so dressed that, after laying, a measurement of the individual joint shall show a width of not more than ½ inch at top and for a depth of 1 inch, and a width of not less than 1 inch in any other part of the joint. The head of the block shall be cut so that it shall not have more than ⅜ inch depression from a straight-edge laid in any direction across the head and held parallel to the general surface of the block.

"Not more than one drill hole shall show on the head of the block and none on the ends, an allowance of not over an average of one block, showing drill hole on side, shall be permitted to a square yard.

"Care shall be exercised in handling the blocks so that the edges. and corners shall not be chipped or broken, as blocks, otherwise acceptable, may be rejected on account of spawling."

Construction

Subgrade and Foundation. The subgrade should be prepared according to the same general directions that have been given in previous chapters, care being taken to obtain a firm bottom formed of good material. Since a stone block pavement is usually the type recommended to take the heaviest kind of commercial traffic, a cement concrete foundation is a prerequisite to successful and economical construction. Instances may be found where the blocks are laid on a sand bed. Unless pavements which are constructed in this manner are given constant attention the blocks soon get out of place, the edges of the blocks become rounded off, the surface becomes very uneven, and ultimately the pavement reaches a condition where it is not much better than one composed of cobblestones. Different methods of constructing concrete foundations have been described in Chapter VI. Although the mixing method is the one generally used, in certain parts of the country the grouting method has been used to a considerable extent in constructing foundations for this type of pavement.

In Germany and Hungary, stone block pavements are generally laid on foundations of well-rolled broken stone.

Kleinpflaster and Durax pavements have been built on concrete foundations. These types of small block pavements have also been built, when subjected to light traffic, on foundations of broken stone, gravel, and on old macadam roads which have been properly shaped up.

The surface of the foundation conforms to the surface of the finished pavement. In Chapter IV will be found formulas giving the amount and distribution of the crown.

Specification. In order to show what is considered to be standard practice in the United States the following specification* is given relative to the preparation of the subgrade and foundation:

*See 1912 Specifications, Association for Standardizing Paving Specifications.

"Any soft and spongy material below the subgrade shall be removed and filled, as directed by the engineer, with sand, gravel, or other material satisfactory to the engineer, and thoroughly rammed and rolled. In excavating, care shall be taken not to disturb the subfoundation, except where necessary to remove the soft and spongy material. The entire subfoundation shall be compact and hard, and the contractor will be required to thoroughly ram and roll it with a roller satisfactory to the engineer unless the latter shall be satisfied that the subfoundation is sufficiently hard without it. After the subfoundation has been prepared to the satisfaction of the engineer, a concrete foundation, 6 inches thick, shall be laid on it. The concrete shall conform to the standard specification for concrete for paving foundations, as determined by this Association. (See Chapter VI.) The grading and subfoundation shall be completed at least 50 feet in advance of the laying of the concrete."

Cushion Layer. A cushion, composed of dry, clean sand, is always spread on the foundation previous to laying the blocks, no matter what their size or shape may be. The purpose of the cushion is to hold the blocks at the bottom, to make practical the laying of blocks of uneven depth, and to take up any small irregularities in the foundation. The thickness of the cushion will depend somewhat upon the character of the blocks used, 2 inches being a common value when the blocks are quite regular in shape.

Laying the Blocks. The blocks are placed on the sand cushion as closely as possible, usually in straight parallel courses with the long dimensions perpendicular to the curbs. The paver uses a special form of hammer, one end of which has a flat blade. He scoops out with the blade end of the hammer, a place in the sand cushion for the block to rest in, places the block and hits it a few taps, so that, on finishing, its surface is even with that of the adjacent blocks. The blocks in one row should break joints with the blocks in another row by at least 3 inches. At street intersections, in order to prevent the traffic of the cross-streets from traveling parallel to the long joints and thus forming grooves,

usually the blocks are laid with their long dimensions parallel to one or both of the diagonals of the square formed by the intersecting streets. The work of laying the blocks is started from the curb lines at each side and progresses towards the center of the street. The blocks may be laid to the desired crown by the use of strings, cross-section stakes, or a board template. After placing the blocks to the proper lines they are thoroughly tamped with a tamper weighing from 60 to 70 pounds until no further settlement occurs. The blocks should lie perpendicular to the sand bed. If any blocks settle more than others they should be taken out and relaid. The joints are then filled with the material which has been selected for this purpose. Fig. 169 is a cross-section of a stone block pavement as constructed by

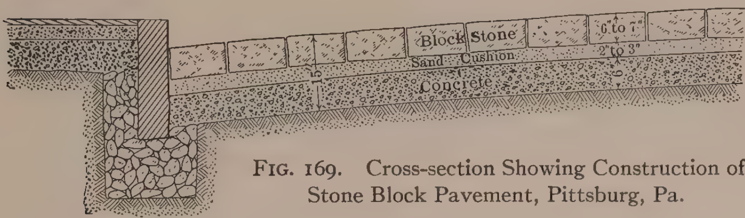


FIG. 169. Cross-section Showing Construction of Stone Block Pavement, Pittsburg, Pa.

the City of Pittsburg, Pa., and serves to show the general arrangement of foundation, cushion layer, and the blocks. The small setts of Kleinpflaster and Durax pavements are laid in circular or parabolic arcs, hence the joints are continually broken. Noise of traffic is thus reduced.

Filling the Joints. Several different materials are used to fill the joints of a stone block pavement. They are sand, tar and gravel, asphalt and gravel, some bituminous material alone, and cement grout.

George W. Tillson, M. Am. Soc. C. E., in discussing the subject of fillers in stone pavements, made the following remarks:*

"The first blocks used for pavements were of stone, and the joints were filled with sand, but such a filling should only be used

* See Trans. Am. Soc. C. E., Vol. LXXV, pages 527 and 529.

for a temporary pavement. A sand filler does not preserve the edges of the blocks from undue wear, and consequently they soon round off, presenting a cobble-stone effect to travel. Water soaks through the joints during rain, dampening the foundation. Urine from horses also saturates the sand at times, giving off unwholesome odors when it evaporates. When concrete foundations were first introduced for stone pavements, it was realized that sand joints would not do. The tar and gravel joints previously referred to were then adopted, the idea being that the gravel would keep the blocks in place, and the tar, filling the spaces in the gravel, would render the entire joint waterproof. Theoretically, this was undoubtedly true, but practically there was often enough fine gravel to prevent the tar from filling the entire joint; or the tar itself, as well as the gravel, would become cold, thus preventing a free flow, the result, in many cases, being a joint which was far from water-tight. Then, after some time, the upper part of the joint would wear, sometimes to the depth of nearly 1 inch, so that the edges of the blocks would wear off, producing what is known as the turtle-back effect, which is almost always seen in old pavements of that character. To use gravel of such a size as would permit the free flow of the tar, made it necessary to have wide joints, which was also conducive to the undue wear of the blocks, often making a rough and unsatisfactory surface, even when the blocks themselves were fairly good.

"Two improvements over the tar and gravel joint have been used: a straight coal-tar pitch or some other bituminous compound, and Portland cement grout. To make the pitch joint satisfactory, it is necessary to lay the blocks close, even stone to stone, and dressed so that there will be no excess spaces to be filled. With narrow joints, the pitch will hold the blocks in a stable position and also prevent the direct transmission of the impact of traffic from one block to another. A stone pavement is bound to be noisy, but one laid in the foregoing manner is thought to be as free as possible from this defect. Laying the blocks close prevents undue wear on the edges, such as is seen with tar and gravel or sand joints. A notable instance of a

pavement of this character, laid during 1911, can be seen on Fourth Avenue, Borough of Manhattan, New York City. Here special requirements were made for both the pitch and the blocks, those for the latter being probably more stringent than for any work of a similar character in the United States. The requirements were lived up to, and the result has been a highly satisfactory pavement.

"Worcester, Mass., was probably the first city to make use of the cement grout joint. The spaces between the blocks were first filled with stone screenings and then poured full of the grout. The result was very satisfactory. As the blocks were gradually made better and therefore laid more closely, the screenings were left out entirely, and grout alone was used. There are advantages and disadvantages in a joint of this kind. It makes a smooth and even pavement, and one that is easily cleaned. It presents little resistance to traffic, and brings the wear of traffic vertically on the top of the blocks, so that the pavement is very durable. As the joints are filled full of the grout, which wears down evenly with the surface, the pavement itself becomes smooth and slippery under wear, both on account of the smooth surfaces of the blocks and because of the lack of joint depressions to give foothold to horses. It is also extremely necessary that the grout should become thoroughly hard before any traffic is allowed on the pavement, otherwise the blocks will be loosened and the permanent set prevented, so that the filling becomes little, if any, better than sand. Pavements thus laid become practically continuous, giving off a metallic noise under traffic. The hardened grout, being a good conductor of sound, transmits the noise readily from block to block. Where the grade is flat, however, and the street is kept free from traffic until the grout has thoroughly set, the pavement will be very satisfactory. It is the smoothest form of stone pavement that has been laid in the United States. Most specifications provide that the street shall be closed to traffic for a period of seven days after the grout has been poured in order to give the latter time to set. A pavement of this kind presents great obstacles to plumbers or subway men. It is exceedingly hard to open, many

of the blocks breaking rather than separating from the next adjacent ones, thus causing a great deal of waste. It is difficult, too, to repave an opening properly, as traffic forces itself on the freshly grouted blocks, thus breaking the bond. The advantages of a pavement of this type are that it is smoother, more durable, and more easily kept in shape than any other; the disadvantages are that it is more slippery, noisier, and harder to repair."

Specifications. The 1912 specifications of the Association for Standardizing Paving Specifications are very complete, both as to the character of the fillers and the methods of application. Since they are thought to be representative of standard practice in this country they are herewith given:

"Depending upon the kind of filler to be used in the joints, the following specifications, A, B, or C, shall govern the use of coal-tar pitch (A), asphalt (B), or cement grout (C).

"(A) Coal-Tar Filler. Immediately after the blocks are laid, sufficient coarse, hot gravel shall be spread over the surface and swept into the joints so as to fill the space between the blocks to a depth of about two inches from the bottom. The blocks shall then be rammed to thoroughly settle and compact the first layer of gravel in the joints, and so as to leave no blocks above or below the general surface of the finished pavement. The joints shall then be poured one-half full with a coal-tar pitch filler, as hereinafter described, and then filled to within ½ inch of the surface with hot gravel and again poured with the filler; this last pouring shall be flush with the tops of the blocks at the joints. The final pouring of the filler shall be immediately followed with a sufficient amount of hot gravel, applied at the joints, to conceal the filler. The gravel shall be clean, washed gravel between ⅛ inch and ⅜ inch in its largest dimensions, not over 25 percent of which shall be of the ⅜-inch size.

"The filler shall also comply with the following test requirements:

(1) It shall have a specific gravity between 1.23 and 1.33 at 60 degrees Fahrenheit.

(2) It shall have a melting point between 120 and 130 degrees Fahrenheit.

(3) It shall contain between 20 and 30 percent of free carbon.

"The coal-tar pitch filler shall be used on the work at a temperature of not less than 250 degrees Fahrenheit, and shall at no time be heated above 325 degrees Fahrenheit.

"In applying the gravel and pitch, care shall be taken that the pavers are closely followed by the filler gang, and in no case shall the paving be left over night (or when work is stopped), without the filling being completed. In case of rain stopping the filler gang before its work is finished, the joints shall be protected by the use of tarpaulins or other means, so as to keep out water, and under no circumstances shall the filler be poured into wet joints.

"(B) Asphalt Filler. The specifications are the same as in the case of coal-tar filler except as follows:

"The asphalt filler to be used in filling the joints between and around the paving blocks and bridge stones shall be a bituminous material, either a natural or artificial, entirely free from coal-tar or any product of coal-tar distillation. It shall be waterproof, free from water or decomposition products, shall adhere firmly to the paving-stones, and shall remain ductile and pliable at all climatic temperatures to which it may be subjected in actual use, and shall not run in the joints in the hottest temperature of summer, nor become hard or brittle through the action of frost.

"The asphalt filler shall conform with the following requirements:

(1) It shall contain not less than 98 percent pure bitumen soluble in carbon disulphide.

(2) Of the total amount soluble in carbon disulphide, 98.5 percent shall be soluble in carbon tetrachloride.

(3) When tested by the Dow method for one minute with a No. 2 needle weighted with 200 grams and operating for one minute at 32 degrees Fahrenheit, it shall have a penetration greater than 25.

(4) When tested for five seconds with a No. 2 needle weighted with 50 grams and operating for five seconds at 115 degrees Fahrenheit, it shall have a penetration not greater than 110.

(5) When tested for five seconds with a No. 2 needle weighted

with 100 grams and operating for five seconds at 77 degrees Fahrenheit, it shall have a penetration between the limits of from 25 to 60.

(6) Its specific gravity at 60 degrees Fahrenheit shall not be more than 1.00.

(7) One-half gram of the material, when made into a ball, shall not melt and drip through an aperture 1 millimeter in diameter at less than 220 degrees Fahrenheit.

"The paving cement shall be heated on the work to a temperature of not less than 400 degrees Fahrenheit, nor more than 450 degrees Fahrenheit, in such quanities as will allow of this temperature being maintained in the kettle during progress of the pouring, and no cement, the temperature of which is less than 400 degrees Fahrenheit, shall be used.

"It shall then be put into a conical can and poured into the joints as hereinbefore described.

"It shall be delivered on the work at least one week before being used and in sufficient quantities to allow of suitable samples for examination and analysis, and such samples shall conform with the above requirements.

"All the joints between the stones shall be filled with this hot paving cement, continuing the pouring until the joints are entirely filled, but no flushing of the pavement shall be permitted.

"(C) Cement Grout Filler. Immediately after the blocks are laid, sufficient gravel shall be spread over the surface and swept into the joints so as to fill the spaces between the blocks to a depth of about 2 inches from the bottom.

"The blocks shall then be rammed to thoroughly settle and compact this layer of gravel in the joints and so as to leave no blocks above or below the general surface of the finished pavement.

"After the pavement has been brought to a uniform surface Portland cement grout shall be poured into the joints until it appears on the surface. The grout shall be broomed into the joints, if necessary to fill the same, and the operation shall be continued as the grout settles, until the joints are thoroughly filled flush with the surface of the blocks, immediately after which

the entire pavement shall be broomed to a smooth surface, sufficient grout being applied to bring said surface even with the highest part of any of the blocks. The blocks shall be wet by sprinkling immediately before applying the grout, if the condition of the atmosphere requires this precaution to be taken.

"The cement grout shall be composed of one measure of the best quality of freshly burned Portland cement to one measure of clean, sharp sand. In the mixing of the cement and the sand, clean, fresh water shall be used to give the proper consistency; care shall be taken not to use an excessive amount of water.

"The grout shall be mixed for this purpose, either in a machine mixer, to be approved by the engineer, or in a box about 4 feet 8 inches long, 30 inches wide, and 14 inches deep, resting on legs of different lengths, so that the mixture will readily flow to one corner of the box, the bottom of which shall be 3 inches above the pavement. The mixture shall be removed from this box to the street surface with scoop shovels, all the while being stirred in the box as the same is being applied. One such box shall be provided for each 10 feet in width of roadway. The work of filling shall be carried forward until an advance of 15 to 20 yards has been laid, when the same force and appliances shall be used to regrout the same space in a like manner excepting that the proportion of the mixture for this second application shall be two parts of Portland cement to one part sand. The work shall be kept lightly sprinkled with water on the surface ahead of the sweepers by means of a sprinkling can, or other suitable device, to avoid the possibility of causing the grouting to become too thick at any point. To insure the penetration of the grout into the joints of the pavement there shall be used, in addition to the brooms, a squeegee scraper, 15 inches to 18 inches in length, on the last application of the grout.

"Within one-half to three-quarters of an hour after the last coat has been applied and the grout between the joints has fully subsided, and the initial set is taking place, the whole surface shall be lightly sprinkled and all surplus mixture left on the top shall be swept into the joints, bringing them up flush and full. After the grouting is done and a sufficient time for hardening has

elapsed so that the coating of sand will not absorb any moisture from the cement mixture, ½ inch of sand shall be spread over the whole surface, and in case the work is subjected to a hot summer's sun, an occasional sprinkling to dampen the sand shall be made for two or three days.

"After the grouting is completed the street shall be kept closed and no carting or traffic allowed until at least seven days have elapsed, on any portion of the street grouted, and the face of the pavement shall be kept moist if the condition of the weather requires this precaution, as may be directed by the engineer. Should the bond between the blocks become broken for any reason during the progress of the work, the joints shall be cleaned out, even if it is necessary to take up and relay the blocks, and such parts so taken up and relaid shall be regrouted and rebarricaded."

The joints in Kleinpflaster and Durax pavements are filled with sand, gravel, cement grout or a bituminous filler.

Examples and Cost of Construction. The estimated cost of constructing stone block pavements of Cape Ann or Quincy granite on a 1 : 3 : 6 Portland cement concrete foundation 5 to 6 inches thick, the joints being filled with trap rock screenings and a 1 : 1 Portland cement grout, is $3.75 per square yard for heavy blocks, and $3.25 for light. The heavy blocks are 10 to 13 inches long, 3½ to 4 inches wide, and 4 to 4½ inches deep. The heavy blocks are laid on a 2-inch sand cushion.

In 1910 the cost per square yard of constructing stone block pavements in Detroit, Mich., is given in the paving report of a special committee of that city, as follows:

Preparation	$1.41
Block	1.79
Haulage	.19
Laying	.45
Inspection	.04
	$3.88

Close-jointed cement grout block pavements have been laid in Newark, N. J., since 1909. The blocks were laid practically according to the specifications of the Association for Standardizing Paving Specifications as previously quoted. The average

cost of 62,773 square yards of work in 1910 was $3.11. In the same year the cost of granite block pavements laid under the same specifications in New Orleans, La., was $3.75 per square yard, in Chicago, Ill., $3.68 per square yard.

In the table which follows is given the character and cost of stone block pavement in several cities throughout the United States in 1911:

TABLE No. 25

From *Engineering and Contracting*, April 3, 1912

City	Square Yards	Cost per Sq. Yd. Incl. Grad.	Foundation		Kind of Filler
			Kind	Thickness Ins.	
Barre, Vt.	3,263	$2.83	Concrete	6	Grout
Boston, Mass.	19,615	2.65	"	6	Pitch
East Providence, R. I.	14,470	2.30	......	....	Sand
Bridgeport, Conn.	7,900	3.13	Concrete	6	Grout
Buffalo, N. Y.	22,593	3.79	"	6	Grout
Rochester, N. Y.	22,489	2.93	"	6	Grout
Jersey City, N. J.	22,959	1.50*	......	....	Sand
Newark, N. J.	79,506	3.10	Concrete	6	Grout
Cleveland, O.	58,600	3.15*	"	6	Pitch
Kansas City, Mo.	23,000	2.98	"	6	Grout
St. Louis, Mo.	23,698	2.60*	"	6	Sand
Baltimore, Md.	11,079	3.61*	"	6	Grout
Seattle, Wash.	31,559	3.50*	"	6	Grout
Portland, Ore.	111,662	3.50*	"	6	Grout

* Does not include grading.

The following table* gives in detail the cost of a Medina block pavement laid in Rochester:

LABOR COST

	Per Square Yard.
Loading and unloading	$0.035
Hauling 1 mile	.035
Distributing blocks	.030
Laying	.060
Filling joints	.060
Foreman at 40 cents per hour, 30 sq. yds.	.013
2 water and errand boys	.007
	$0.240

* Gillette's "Cost Data," p. 374.

COST OF PAVEMENT

	Per Square Yard.
⅓ cu. yd. street excavation	$0.15
6-inch concrete foundation	0.50
1/18 cu. yd. sand cushion in place at $1.08	0.06
Medina block (6 in.) f.o.b. Albion, N. Y.	1.15
Freight to Rochester	0.07
Unloading, hauling, and laying	0.24
1.5 gals. tar at 10 cents a gallon	0.15
1/50 cu. yd. sand for joints	0.02
	$2.34
Profit	0.26
Total	$2.60

Foreign Pavements. Pavements in Liverpool of blocks approximately 3 by 6 by 6 inches in size laid on a sand cushion on a 7-inch concrete foundation, the joints being filled with fine dry gravel and a mixture of pitch and creosote oil, cost about $3 per square yard.

In Birmingham and Enderby, England, blocks which are approximately 4-inch cubes are laid on a ½-inch sand cushion on a 6 to 7½-inch Portland cement concrete foundation. The blocks are laid in courses which make an angle of 45 degrees with the curb lines and are grouted with a Portland cement grout. This type of pavement is estimated to have a life of twenty years and costs $3.50 per square yard.

In France the blocks are laid on a sand cushion from 2¼ to 4 inches in thickness on a cement concrete foundation averaging about 6 inches in thickness. The blocks are generally laid with the courses at right angles to the curb lines. The joints are filled with sand which is well broomed in after the blocks have been finally tamped to place. More sand is spread and worked into the joints by sweeping and flushing. The cost of pavements constructed in this manner in Paris varies from $3.40 to $3.80 per square yard.

Kleinpflaster. In Germany a Kleinpflaster pavement, made from granite or basalt blocks, on a gravel base with a sand filler costs from $1.06 to $1.48 per square yard. Constructed on a

10- to 12-inch stone layer the cost in one instance was $1.90 per square yard.

Durax. H. E. Stilgoe, City Engineer of Birmingham,

FIG. 170. Construction of Durax Pavement at Illford, England.

England, has obtained excellent results by laying 2¾-inch granite cubes on a 1½-inch bed of bituminous mastic. The

FIG. 171. Surface of Durax Pavement on the Chelsea Embankment, London.

blocks were well rammed into this mastic cushion and the joints were filled with a mixture of pitch and oil. The cost of this

pavement was $1.93 per square yard. The construction of the Durax pavement is shown in Fig. 170, and its surface in Fig. 171.

MAINTENANCE

The maintenance of a stone block pavement, if properly constructed, is negligible for the first few years. The life of a granite block pavement constructed on a concrete foundation having a tar and gravel joint filler is estimated as about twenty-five years. When the blocks become worn so that the surface is extremely uneven, it is possible to take the blocks up, redress them and relay them as a new pavement. The specifications of the Borough of the Bronx, City of New York, state in regard to relaying granite block pavements: "When redressed granite blocks are to be laid, the old blocks shall be taken up and re-dressed up to the required shape and dimensions. If the old blocks, when redressed, are not sufficient to pave the area designated, the contractor shall supply additional blocks to make up the deficiency, the cost of taking up, redressing and relaying the old blocks and the cost of furnishing and laying any additional blocks required shall be included in the price bid for redressed granite block pavement." The cost of relaying granite block paving, including a concrete base and recutting blocks, is estimated at $2 per square yard. The cost is estimated to be about $2.50 per square yard when not more than 25 percent of new blocks are substituted for the old ones which are unfit for relaying.

The average annual maintenance cost of stone block pavements will vary from about 1/10 to 2 cents per square yard.

CHARACTERISTICS

The chief advantage of a stone block pavement is its durability. Such a pavement if properly constructed is able to withstand the heaviest kind of traffic. It is well adapted for use on those streets which are subjected to the heavy traffic of the docking districts. A stone block pavement is about the only

permanent pavement which can be used on very steep grades and at the same time furnish a good foothold for horses. In 1910 there were several instances where it was used on grades of 11 percent and in one case the grade was about 19 percent. The pavement, as now constructed, may be slippery when the stones get rounded off from wear or sometimes when a grout filler is used the pavement may be somewhat slippery soon after completion, particularly when it is slightly wet. It has been the experience in Europe that pavements constructed with block of porphyry are very slippery when the blocks become worn, and the use of blocks of this material is being discontinued in Paris. The chief defects of a stone block pavement are its rough and noisy surface. The kind of joint filler used influences these characteristics to a great extent. If built on an unyielding foundation and the blocks are laid in the beginning with an even surface and the type of filler used is one which will not readily work out of the joints, the pavement should not become rough for a considerable period of time. When, however, the blocks get out of place and the filler does not protect the edges of the blocks from wear, the blocks become rounded off at the joints and a rough surface ensues. When in this condition the pavement is not sanitary since it is hard to clean and the joints afford a place for the collection of all kinds of filth.

CHAPTER XVIII

BRICK PAVEMENTS

Development. Brick pavements were probably first constructed in Holland. Although brick pavements have been constructed there for over a century, the use of this type of construction in other parts of Europe is very limited. The first piece of brick pavement in the United States was a short experimental section laid in Charlestown, West Virginia, in 1870. This was followed by another experimental piece laid in Bloomington, Illinois, in 1875, and a few other sections laid from time to time, up to 1885, in different cities of the Middle West. The use of this kind of pavement then began to increase rapidly, and at the present time there are very few large cities in the country that do not have some of their streets paved with this material. A census taken of the permanent pavements laid in 1910, in the United States, showed that brick was one of the most popular forms of pavement, considering the number of cities that have used it. From this census it was found that while sheet asphalt was first from the standpoint of yardage in the 460 cities reported, brick was a close second. It is natural that the greatest yardage should occur in those cities throughout the Central States since this locality abounds with clay deposits suitable for the manufacture of paving brick and is devoid of road building stone.

The first brick pavements were constructed without a concrete foundation and with a sand filler. In the development of this type of pavement which has taken place since 1885, considerable attention has been given to the manufacture of the brick itself. The present practice also commonly requires a concrete foundation and generally some other filler than sand.

The Brick

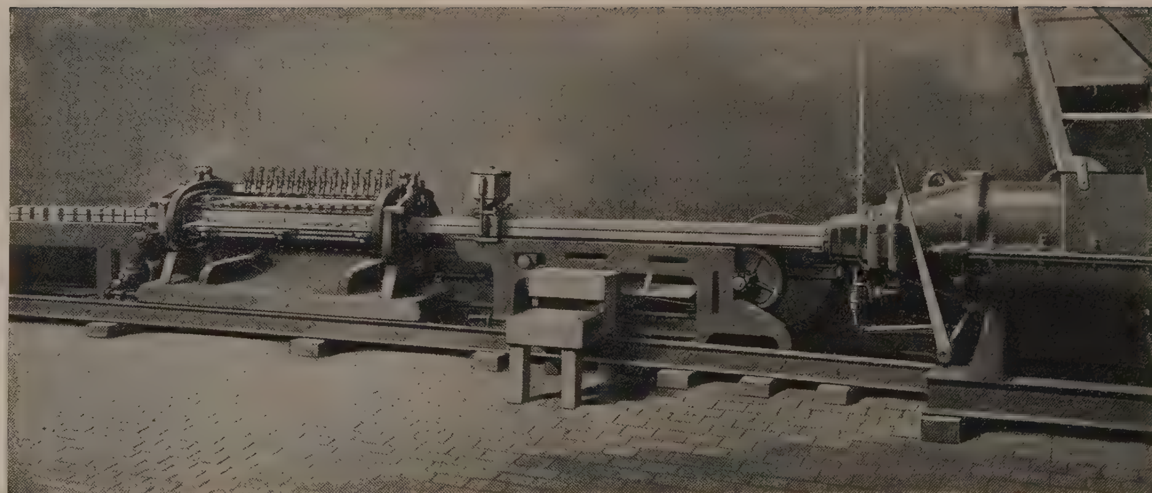
Brick Clays and Shales. Clays for making vitrified bricks are not often found in a natural state. A clay for this purpose should be fusible, plastic, and capable of being heated to a high temperature without losing its shape. Surface clays, therefore, are very little used, although they are extensively employed in the manufacture of building brick. Some potters' clay, if quite impure, may make a fair quality of paving brick.

The material from which most of the paving brick is now made is a shale. Shales are chemically the same composition as clays, but have become hardened and have a laminated structure, being similar in appearance to slates. They are found in large deposits in stratified beds. To make a satisfactory vitrified paving brick a shale should have approximately the following composition which is an average of fifty shales from different sources that are used for this purpose.

Composition of Paving Brick Shales

	Average Percent.
Silica (SiO_2)	56.0
Alumina (Al_2O_3)	22.5
Ignition loss (mainly H_2O)	7.0
Moisture (H_2O)	1.5
Total nonfluxing constituents	87.0
Sesquioxide of iron (Fe_2O_3)	6.7
Lime (CaO)	1.2
Magnesia (MgO)	1.4
Alkalies (K_2O, Na_2O)	3.7
Total fluxing constituents	13.0
Grand total	100.0

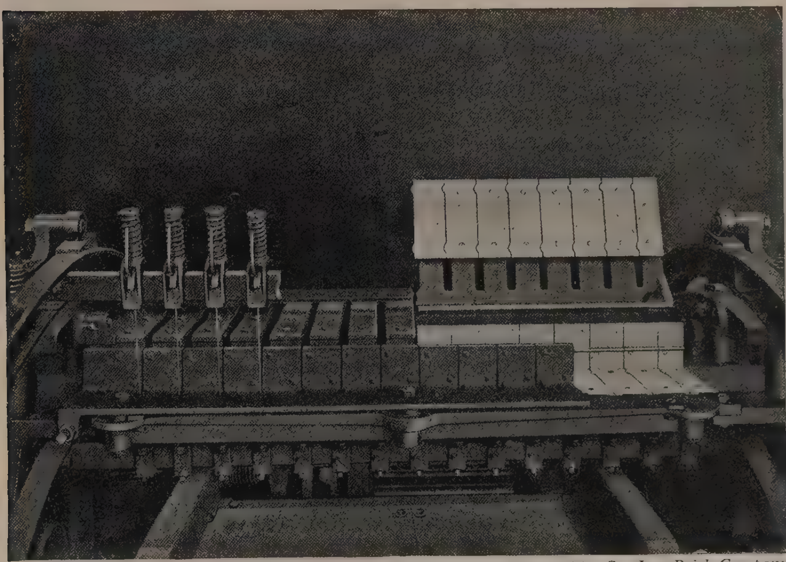
It is very important that the condition of the iron in the shale should be known, as successful burning depends upon this element. When the lime is present in the form of a silicate it is extremely valuable as a flux, but when it occurs in the form of a carbonate the strength of the brick will be greatly affected. An excess of silica will cause weakness and brittleness, while an excess of alumina will cause shrinking, cracking, and warping.



Courtesy of the Dunn Wire-Cut-Lug-Brick Company.

FIG. 172. Die and Brick Cutting Machine. Plant of the Deckman-Duty Company.

Making the Brick. The shales are usually obtained by open pit excavations, a steam shovel being used if the plant is large enough to warrant an outfit of this kind. The excavated material is hauled in small dump cars. About 2 cubic yards of shale are needed per one thousand brick. The shale is usually crushed in dry pans which are rolls 4 feet in diameter and 12 inches wide running within a revolving pan 9 feet in diameter that has a grated bottom. The shale as it is crushed is screened



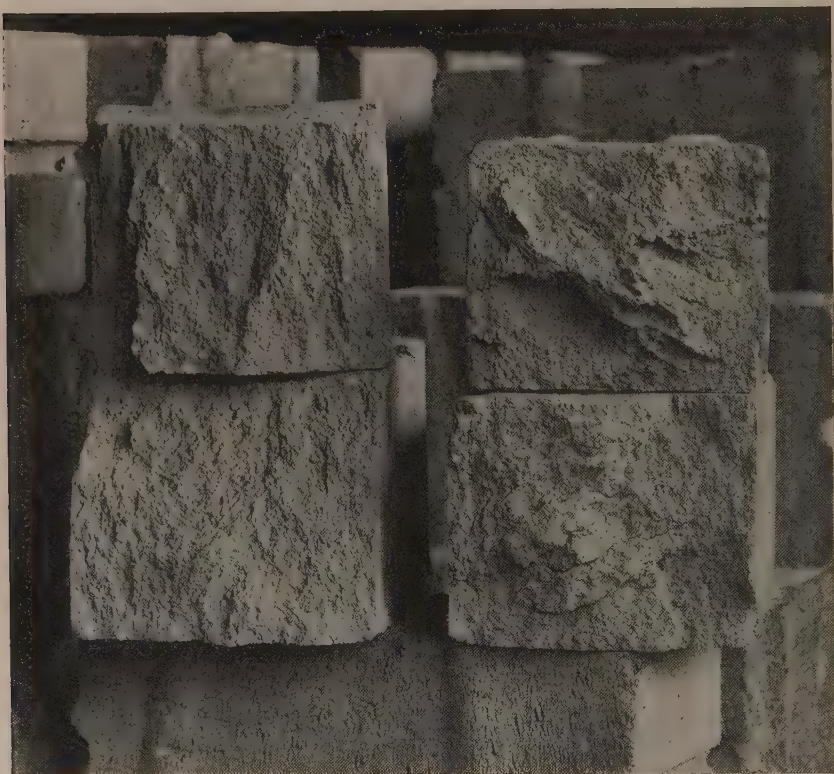
Courtesy of the Dunn Wire-Cut-Lug-Brick Company.

Fig. 173. Brick Cutting Machine. Showing Details of Construction in Four Sections. Plant of the Deckman-Duty Company.

through a 4 to 8 mesh screen. The finer the clay is crushed, the stronger will be the resulting brick, and a screen having 10 to 16 meshes per linear inch would probably be better on this account. The screened material is mixed with water in a pug mill to the right state of consistency. The pug mill is a long trough through which runs a heavy revolving shaft equipped with a series of wide blades.

Paving brick are usually made by the so-called stiff mud process. The plastic clay as it leaves the pug mill is forced by

an auger through a die which forms a continuous bar of stiff clay of the desired cross-section and this is cut into bricks of the desired size by an automatic cutter. The dies and cutting apparatus are so arranged that the bricks are cut off



Courtesy of the Dunn Wire-Cut-Lug-Brick Company.

FIG. 174. Broken Wire-Cut-Lug (at left) and Repressed Bricks (at right).

with a side cut. The bricks are then treated in either of two ways. They are in some cases repressed in a die, during which process the edges of the brick are rounded off and lugs, grooves and the brand mark are stamped on the sides of the brick. Instead of subjecting the brick to repressing, lugs are cut in the sides by means of wires traveling through guides. See Figs. 172 and 173.

The lugs are therefore formed at the same time the continuous bar of clay from the pug mill is cut up. Brick made in this way are called wire-cut-lug-brick. They are not repressed and the edges are not rounded off. The function of lugs and grooves on a paving brick is to provide space between the bricks for the filler. The brand marks are sometimes raised and serve the same purpose as lugs. One advantage of the wire-cut-lug-brick over the repressed brick is that the lugs are generally more uniform in the former than in the latter. Repressing also changes the internal structure of the brick as is evidenced by Fig. 174, in which the right-hand cut represents a broken repressed brick and the left-hand cut a broken wire-cut-lug-brick.

The brick, as they leave the cutting or repressing machine, are piled on cars in a manner that will allow free circulation of air between them, and are then hauled to a drying chamber which is heated either by hot air or by steam pipes. It takes from eighteen to sixty hours to dry the bricks properly, depending upon the kind of clay and the plant arrangement. The down draft kiln is best adapted to the manufacture of paving brick. The bricks are burned from seven to ten days at a temperature of from 1,500 to 2,000 degrees Fahrenheit. At 1,200 degrees Fahrenheit a chemically combined water is driven off and the clay begins to shrink. When a temperature of 1,500 to 1,800 degrees Fahrenheit is reached, the clay shrinks about 5 to 10 percent more. From this temperature to one from 100 to 600 degrees Fahrenheit higher, the clay completely coalesces or vitrifies. It is at this point that the brick, when slightly cooled, has obtained its maximum toughness and cross breaking strength. The temperature which is necessary to vitrify the brick is maintained in the kiln until the bricks are thoroughly heated through to the center. The kiln is then tightly closed and the bricks are allowed to cool off very slowly. This part of the process is called annealing, and to get a tough brick requires from seven to ten days cooling in the kilns. The bricks are then sorted into different lots, the No. 1 paving brick generally being found in the uppermost layers in the kiln.

The color of the paving brick is governed largely by the clay

from which the brick is made, the degree of temperature which is reached in vitrifying the brick, and the kind of fuel that is used. The outside color of a brick is also changed by the sand that is used to prevent the brick from sticking to the dies or to each other in the kiln. Salt glazing also affects the outside color of the brick. To tell anything about color, the brick should be broken through. As a rule, shales make a brick either red or brown in color, while the impurer clays give different shades of buff.

Size and Character of Brick. All brick are specified to be No. 1 pavers. Two sizes of brick are commonly used; one size is 2½ inches in width, 4 inches in depth, and 8½ inches in length, and the other size is 3½ inches in width, 4 inches in depth, and 8½ inches in length. Although both sizes are called bricks, the larger size is sometimes designated as blocks to distinguish it from the smaller size. Specifications usually allow a variation of ⅛ inch in width and depth, and no variation in length of more than ½ inch. When the edges of the brick are rounded the radius should not exceed ⅛ inch. It is also stipulated that only brick with raised lugs on one side, not to exceed ¼ inch in height, shall be used. Practically all specifications require that the brick should be thoroughly annealed, tough, durable, regular in size, shape and evenly burned. When broken, the brick should show a dense stone-like body uniform in size, free from lime, air pockets, cracks or marked laminations. Kiln marks should not exceed 3/16 of an inch, one edge at least to show but slight marks. All bricks so distorted in burning as to lay unevenly in the pavement should be rejected. The brick should always be carefully unloaded by hand and stacked in piles at the sides of the streets outside of the limits of work. The number of brick that it will take to make a square yard of pavement of course depends upon the size of brick and the width of joints. The table on following page is taken from Gillette's "Cost Data."

Testing the Brick. It is possible by means of tests to determine the quality of a brick proposed for use in a pavement. The most important test made is the rattler test which is really an abrasion test and gives some indication of how the brick will

Size of Brick	No. of Brick Per Square Yard. With 1/8 Inch Joints.	No Allowance for Joints.
2¼ by 8 by 4, laid flatwise	67.1	72.0
2¼ by 8¼ by 4, laid edgewise	65.1	69.8
3¼ by 8½ by 4, laid edgewise	44.5	46.9
2½ by 8½ by 4, laid edgewise	57.2	61.0
3 by 9 by 4, laid edgewise	45.5	48.0

wear when subjected to the action of traffic. The specifications of the American Society for Municipal Improvements call for no other test than the rattler test since it is believed that if a brick is sufficiently hard and tough to pass this test successfully, it is of such a quality that it will successfully meet the requirements of other tests. The other tests which are sometimes made are the absorption test and the cross bending test. In selecting bricks for a sample to be tested, care should be taken to choose bricks which are in no way unsound or that would be culled from those to be used in the pavement.

The Rattler Test. The standard rattler is a machine which consists essentially of an iron barrel about 28 inches in diameter and of about the same length. Fourteen steel staves comprise the sides of the barrel, and two heads with trunnions serve as the ends. The heads and staves are lined with metal plates which can be removed when worn and replaced. The barrel is supported on a cast iron frame and is driven by means of gears and a belt pulley so as to revolve with its charge at a rate of from 29½ to 30½ revolutions per minute. The abrasive charge consists of two sizes of spherical shot, the larger size being about 3.75 inches in diameter when new and weighing about 7½ pounds each, the smaller size being 1.875 inches in diameter and weighing 0.95 pounds each. Ten of the large shot are used and enough of the small shot to bring the weight up to a total of 300 pounds. When a large shot is worn so that it falls to 7 pounds, or when a small shot is worn so that it will pass through a circular hole having a diameter of 1¾ inches in a cast iron plate ¼ inch in thickness, the worn shot should be replaced with a new shot. The iron of which the shot are composed is of the utmost importance. Standard shot should have the following composition:

Combined carbon.........Not less than	2.50	percent.
Graphitic carbon.........Not more than	0.10	"
Silicon...................Not more than	1	"
Manganese...............Not more than	0.50	"
Phosphorus..............Not more than	0.25	"
Sulphur.................Not more than	0.08	"

The bricks are first dried for a period of at least three hours at a temperature of 100 degrees Fahrenheit. Ten bricks are weighed and then placed in the rattler with the charge of spherical shot. The rattler is revolved for 1,800 revolutions at a rate of 29½ to 30½ revolutions per minute. The bricks are then taken out and their loss in weight is determined. No piece of brick should be weighed which is under one pound in weight. The bricks should be examined as to their condition, and from the weights before and after rattling the percentage of loss can be computed. The table which follows gives the results of a few tests made on paving brick in the laboratory of the Highway Division of the Maryland Geological Survey during 1908 and 1909.

TABLE No. 26

PERCENTAGE LOST IN RATTLER 1,800 REVOLUTIONS

Name	Color	Percentage Lost
Mill Hall Brick Works	....	40
Porter Block	Dark Red	21
Mack	Buff	16
Mack	Light Buff	16
Mack	Light Buff	17
Mack	Light Buff	18
Mack	Light Buff	25
Thornton	Dark Red	28
Porter	Buff	23
Metropolitan Block	Dark Red	19
Collinwood Block	....	28
Fairmont Block	Salmon	19
Maxwell Block	Dark Red	17
Glen Gary Block	....	29
Patton Block	....	20

The following requirement is quoted from the 1911 specifications of the American Society for Municipal Improvements:

"The brick shall not lose of their weight more than 22

percent for a heavy, 26 percent for a medium, and 28 percent for a light traffic street, after being submitted to the rattler test. Samples of brick of uniform shape and appearance shall be taken from each car (estimated at 10,000 brick). Brick having a defect that would cull them shall not be used. Three grades of samples shall be tested, one of the softest, one of the medium, and one of the hardest burned. If all of the tests overrun the above percentage of loss, the car shall be rejected. If one or two of the tests overrun, another test of said grade or grades shall be made. Should any one of these tests overrun the specified percentage of loss, the contractor may cull said grade, provided they do not exceed 10 percent of the amount of brick in the car, and deliver the balance on the pavement. Otherwise, the whole car will be rejected."

Absorption Test. The absorption test is made on five bricks which have been through the rattler test and whose weights are known. They are immersed in water for forty-eight hours and then weighed again. From these weights before and after immersion the percent of water absorbed can be computed.

Cross Breaking Test. The cross breaking test is made by placing a brick on edge, as laid in the pavement, on supports which are 6 inches apart. The breaking load is applied at the center of the brick. The average of the result on ten bricks is used in computing the modulus of rupture $R = \frac{3WL}{2bd^2}$, where W is the average breaking load in pounds, L the length between supports expressed in inches, b the breadth, and d the depth in inches.

Construction

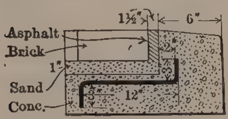
Subgrade. The subgrade should be prepared with the same care that is shown in building any type of improved pavement. All poor material should be replaced with material of a good character and the whole thoroughly compacted to correspond to the shape of the finished surface of the pavement. Means for proper drainage should be provided as described in Chapter V.

Foundation. On city streets it is generally customary to construct a brick pavement on a cement-concrete foundation, specifications for which are given in Chapter VI. An average thickness for a foundation in a location of this kind is 6 inches. In constructing brick pavements on roads without built-up districts in Ohio and in Pennsylvania, a 4-inch concrete foundation is usually specified. Some brick pavements have been successfully built in Allegheny County, Penn., by using an old telford base

Fig. 175. Result of Constructing a Brick Pavement on a Sand Foundation.

as a foundation. It is believed by some engineers that in locations where the traffic is not heavy, either broken stone or good gravel well compacted will serve satisfactorily as a foundation. This is not considered good practice. If the bricks are laid directly upon a sandy subgrade the surface will soon become uneven under any large amount of traffic. See Fig. 175. The National Paving Brick Manufacturers' Association specify two kinds of foundation, one of concrete and the other of No. 2 paving block laid flat. The latter foundation is constructed by covering the subgrade with a layer of sand 2 inches in thickness and laying the bricks flatwise upon this sand bed, filling the joints with a cement filler composed of two parts of clean

sand and one part of Portland cement. This type of foundation has given satisfactory results in some instances, but it is almost as expensive as concrete to construct. When a brick pavement is to be laid where no curbs exist, a concrete shoulder is built which serves to prevent the brick from moving laterally. Fig. 176 shows the standard section used by the New York State Department of Highways. The foundation is constructed with the same crown as the surface. Formulas for the amount and distribution of the crown have been given in Chapter IV.



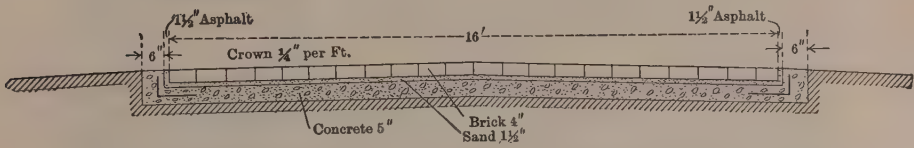


FIG. 176. Standard Section of Brick Pavement, New York State Department of Highways.

CUSHION. A sand cushion, which shall have a thickness of 1½ to 2 inches when completed, is spread on the foundation and carefully levelled off by means of a template so that the surface of the sand is parallel to the finished surface of the pavement and then rolled with a light roller. See Fig. 177. A practical method of constructing the sand cushion is well described in the 1912 specifications of the Association for Standardizing Paving Specifications.

"Over the foundation, which must be thoroughly cleaned, shall be spread to a uniform depth of 1½ inches (after rolling) a cushion of clean, sharp sand, free from loam or foreign matter. The sand must pass a ¼-inch screen. The cushion shall be carefully shaped to a true cross-section of the roadway by means of a template having a steel faced edge, covering at least one-half of the width of the brick work, and so fitted with rollers as to be easily drawn on the curb and guide timbers or rail. Guide timbers shall be 1½ inches by 4 inches by 16 feet, dressed on two sides, laid to a true surface in the center of the street and also next to the curb, if curb cannot be used.

"Before shaping the cushion a ½-inch strip shall be laid on the curb, and guide timbers or rail, and the template drawn over the same, after which the ½-inch strip shall be removed, the cushion slightly moistened and rolled over its entire surface with a hand roller. The roller shall not be less than 36 inches in diameter, 24 inches in width, and weighing not less than 10 pounds per inch of width, and have a handle 12 feet in length. After

Courtesy of the Dunn Wire-Cut-Lug-Brick Company.

FIG. 177. Smoothing off Sand Cushion.

rolling, the template shall be drawn over the curb and guide timbers or rail, to complete the cushion. The cushion shall be prepared at least 50 feet in advance of the brick laying."

LAYING THE BRICK. The bricks are laid on the sand cushion generally at right angles to the curb except at street intersections when they are laid on special lines as directed. If the bricks are laid across the intersection on lines at right angles to the center line, as in the rest of the street, it is apparent that the traffic

entering from the cross street will travel in a direction parallel with the long side of the bricks. This causes a greater wear at

FIG. 178. The Herring-Bone Method of Laying Brick Pavement

FIG. 179. One Method of Laying Bricks at Street Intersections.

the joints than when the bricks are laid as in Figs. 178 and 179. The bricks are sometimes laid in all parts of the street as shown in Fig. 178.

When the bricks are laid at right angles to the curb, they are placed on edge close together with the joints broken by at least 3 inches. Care should be taken to always place the lug sides in the same direction. The bricks are laid either from curb to curb or from car track to curb. On the completion of every fourth course, the brick should be driven together so as to secure tight joints and straight courses. The end joints are made tight by the use of a bar between the end of each row and the curb. Specifications usually require that a section which contains more than 10 percent of culls shall be taken up and

FIG. 180. One Method of Laying Brick Pavement Between Rails.

relaid with good brick. Neither is the use of any bats or broken bricks allowed except next to the curbs or street-car tracks. To avoid disturbing the sand cushion the laborers should stand on the bricks as they are laid. There are several different methods of arranging the bricks adjacent to and between car tracks. Fig. 180 shows one method where a wide mortar joint has been used outside of the rail. Usually it is possible to lay the brick much closer to the rail than is indicated by this photograph. The required crown of the pavement is obtained by the aid of strings, stakes or board templates. Fig. 181 shows an

alley section of brick pavement as built in Pittsburg in cases where there are no sidewalks. Fig. 182 shows the section of the standard brick pavement as built in this same city.

Rolling. When the pavement has been prepared as above described, and thoroughly swept, it is ready for rolling. A roller

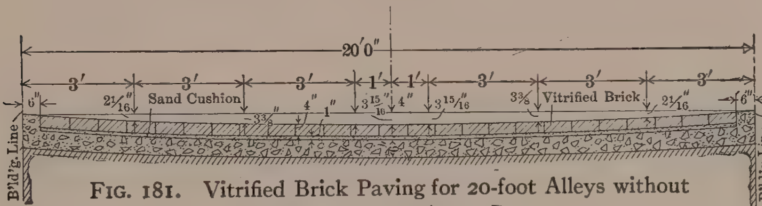


FIG. 181. Vitrified Brick Paving for 20-foot Alleys without Sidewalks in Pittsburg, Pa.

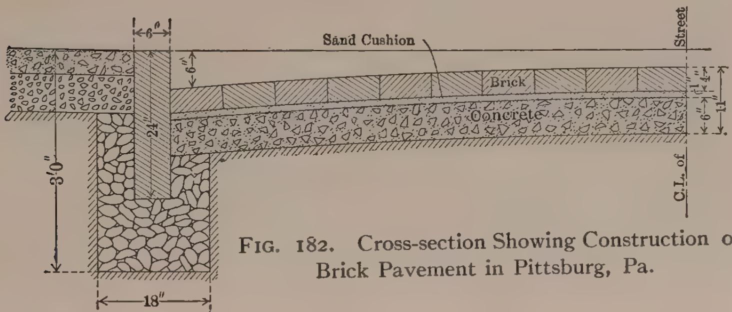


FIG. 182. Cross-section Showing Construction of Brick Pavement in Pittsburg, Pa.

weighing not less than 3 nor more than 5 tons is generally used. Before rolling the brick next to the curb they are tamped to grade with a wooden tamper. Rolling is then commenced near the curb, the roller traveling parallel to the curb back and forth at a slow speed and gradually working across the surface towards the center. When the center is reached, the roller starts at the opposite curb and rolling again progresses to the center as before. After the first passage of the roller, it is possible to work it at a faster speed without danger to the pavement. Rolling is continued as described until the bricks are firmly fixed. Cross rolling is usually required wherein the roller travels in a direction at 45 degrees from curb to curb and then in the

opposite 45-degree direction. Any broken or unsatisfactory brick which are found during the work of rolling should be replaced. Upon completion of the rolling, the surface may be tested with a 10-foot straight edge. Some specifications require the removal and relaying of any parts that show a depression exceeding ¼ of an inch when tested by this method.

Expansion Joints. To allow for expansion of the pavement it is common practice to insert boards between the curb and the pavement which will provide a space from 1 to 1½ inches wide. After the pavement is otherwise completed, the board or boards are removed and this space is thoroughly cleaned out and filled with a bituminous filler. Some specifications also provide for a transverse expansion joint constructed in a similar manner at a distance of every 25 to 50 feet along the street. Trouble is sometimes encountered in removing the boards, particularly where transverse expansion joints are constructed. If the pavement is grouted, unless the board is removed before the grout sets, it may be held fast with the grout that has flowed around it. If the board is taken out before the grout has set, there is a chance of disturbing several rows of blocks on either side of the joint. Moreover, since the board used in the transverse joint must be of a depth which will allow the pavement to be rolled, some difficulty may be experienced on this account, since it is hard to get hold of it to remove it. In pavements built with a grout filler the transverse expansion joints are sometimes temporarily filled with damp sand well packed in the joints. The sand is more readily removed than the boards.

Transverse expansion is sometimes provided for in a grout-filled pavement by filling with a bituminous filler the joints of four to six adjacent rows of blocks about every 25 feet along the street. Unless great care is taken in providing for the expansion of the pavement serious trouble may ensue, particularly where the pavements are subjected to marked changes of temperature. If the pavements are constructed in the hottest months of the year, the bricks, being in an expanded condition when laid, will not expand as much after the pavement is constructed as when they

are laid in a cold season. When a brick pavement cannot expand, the brick arch up over the sand cushion. The pavement under this condition becomes extremely noisy, and frequently cracks are formed in the surface. In some cases the expansion is great enough to force the pavement up several feet with consequent rupture of the surface.

Joint Fillers. After the pavement has been rolled and otherwise completed the joints should be filled with some suitable

FIG. 183. Poor Brick in a Cement Grout-filled Pavement.

material. Sand, cement grout, coal-tar pitch and asphalt are the different materials which are used.

Sand was used for a joint filler in the earliest type of brick pavements. In many places where traffic was not heavy, it was successful, but it does not protect the joints from wearing to any great extent.

Cement grout filler is strongly recommended by the National Paving Brick Manufacturers' Association. This type of filler, however, is extremely difficult to apply and unless properly applied successful results cannot be expected. To quote Will P. Blair, Secretary of the National Paving Brick Manufacturers' Association, "The following practices have come under my

observation: I have seen the filler dipped from the mixing box with a bucket and carried many steps. In such case, the sand was on its way to the bottom of the bucket and the cement was making for the top.

"I have seen the mixture placed in a cradle or rocking box and in the time intervening the turning of the box, the sand and cement were undergoing a like separation, and as the box was

FIG. 184. Chipping Out of Grout Filler in the Joints by Horse-drawn Traffic.

turned the richer mixture of cement flowed ahead and the weaker and sandy portion remained near the box.

"I have seen the water applied before the mixture, in a dry state, reached an even shade, thus preventing the proper adhesion of the particles.

"To remedy the thickening of the mixture, I have seen it entirely ruined by throwing upon the street the water from an open nozzle, which served only to float the cement away from the sand.

"I have seen the mixture put upon the street much faster than it could be swept in.

"I have seen the mixture prepared in a dry street in large quantities at intervals of a few feet upon the brick, and the water

applied and the sweeping-in process undertaken simultaneously.

"I have seen the mixture made up in such large batches that it required a sweeping of several feet before it could be made to disappear in the interstices. In such cases, the last that went in was but very little better than pure sand.

"I have taken a quantity of sand from the supply to be used for filler purposes and found that it contained 33 percent of soil. Thus I might enumerate for hours the manner, method,

FIG. 185. Longitudinal Expansion in a Grout-Filled Pavement.

and means of applying the cement filler in the interstices of a brick street, each and every one of which was but to insure failure, and in none of which is economy to the contractor subserved."

Trouble which may arise from expansion of grout-filled pavements has already been mentioned. Fig. 183 shows a poor brick in a grout-filled pavement. To remove this brick will probably require the destruction of at least two of the adjacent bricks. Fig. 184 shows how the cement grout is chipped out between some joints by the horse-drawn traffic. Fig. 185 shows a grout-filled pavement which has expanded longitudinally and slightly arched up at more or less regular intervals, the limits of

which are marked by the dark transverse streaks in the photograph. Fig. 180 shows a cement grout-filled pavement. Fig. 187 is a construction view showing the way the grout is applied in filling the joints according to the latest approved methods, while Fig. 188 shows a grout surface finish being applied.

The use of some type of bituminous filler presents several advantages. No transverse expansion joints are necessary and a large amount of the expansion troubles are done away with.

Courtesy of the Dunn Wire-Cut-Lug-Brick Company.

FIG. 186. Cement Grout-Filled Wire-Cut-Lug-Brick Pavement on New York State Highway.

The pavement can be used as soon as it is constructed, whereas when a grout filler is used, the pavement must be kept closed to traffic for a period of from ten days to two weeks. Another advantage of the bituminous filler is that in making any openings in the pavement, the bricks can be taken out with less breakage than where joints are filled with a cement grout. Due to the

fact that there is very little trouble from expansion, the pavement is less noisy. Fig. 189 is the surface of a brick pavement constructed with a bituminous filler and shows that the protection afforded the edges of the bricks is excellent. Fig. 190 shows a joint filler can, which is conical shaped and equipped with a

Courtesy of the Dunn Wire-Cut-Lug-Brick Company.

FIG. 187. Application of Cement Grout Filler.

rod to regulate the flow of the material. With this type of can, excellent results can be obtained.

Specifications. The requirements for both cement grout and bituminous fillers, as included in the 1912 specifications of the Association for Standardizing Paving Specifications, follow:

"Portland Cement Grout Filler. The filler shall be composed of one part each of fine, clean, sharp sand and Portland cement. All cement used for this work must stand the test as approved and adopted by the Association for Standardizing Paving Specifications. The sand shall pass a No. 20 standard

Courtesy of the Dunn Wire-Cut-Lug-Brick Company

FIG. 188. Application of Cement Grout Surface Finish.

FIG. 189. Brick Pavement with Bituminous-Filled Joints.

sieve. Sand shall be measured in a box having the same cubical contents as one sack of cement.

"One sack of cement with an equal amount of sand shall be thoroughly mixed together dry in a box 4 feet 8 inches long, 30 inches wide, and 14 inches deep, resting on legs of different lengths, so that the mixture will rapidly flow to the lower corner of the box, the bottom of which shall be 3 inches above the pavement. One box shall be used for each 14 feet in width of roadway, and at least two boxes must be used in all cases. After the cement and sand have been thoroughly mixed until the mass assumes a uniform color, enough clean water shall be added to obtain a grout that will give the best results. From the time the water is applied until the last drop is removed and floated into the joints of the pavement, the mixture must be kept in constant motion. Before the grout is applied the brick shall be thoroughly wet by being gently sprayed.

"The grout shall be removed from the box with scoop shovels and applied to the brick in front of the sweepers, who shall rapidly sweep it lengthwise of the brick into the unfilled joints, until the joints are filled to within not more than 1 inch of the top of the brick. After the grout has had a chance to settle into the joint and before the initial set develops, the balance of every joint shall be filled with a thicker grout, and, if necessary, refilled, until the joints remain full to the top. After this application has had time to settle and before the initial set takes place, the pavement shall be finished to a smooth surface, with a squeegee or wooden scraper, having a rubber edge which shall be worked over the brick at an angle with the brick. When completed and the cement has received its initial set, the pavement shall be covered with a ½-inch layer of sand, which shall be frequently sprinkled in warm weather. No travel shall be permitted on the pavement for a period of from seven days after grouting, or longer, as the engineer may require on account of weather conditions. Ample barricades and watchmen shall be provided by the contractor for the proper protection to the grouting."

"Coal Tar Paving Pitch Filler. The joints or spaces be-

tween the bricks and the curb, railroad tracks, around manholes, etc., shall be filled with coal tar pitch, which shall comply with the following requirements:

"When in place in the pavement, it shall be of such character that it will adhere firmly to the paving block and to the curb, and shall be sufficiently plastic to allow for the contraction and expansion in the pavement without developing cracks in the

FIG. 190. Asphalt Filler Pouring Can.

joints. It shall be proof against action by water and all acids or alkalies to which the pavement may be exposed. The filler shall be such that it retains its consistency under extreme temperature. The free carbon shall not be less than 25 percent nor more than 40 percent. The specific gravity shall not be less than 1.23 nor more than 1.30 at 60 degrees Fahrenheit. It shall have a melting point varying not more than 5 degrees from 135 degrees Fahrenheit, determined by the cube method.

"The filler shall be heated and poured into the joints to the full depth thereof, at a temperature of not less than 300 degrees Fahrenheit, nor greater than 350 degrees Fahrenheit. All joints

shall be completely filled to the top. The top dressing of sand shall be spread over the pavement immediately after the filler is applied and while it is still soft. In cold weather the sand shall be heated so as to readily bond with the pitch. Extra care shall be used at the gutters and around the catch basins, etc., to effectually prevent the leakage of water into the sub-roadway."

"Asphalt Filler. The interstices of the brick shall be completely filled with an asphalt filler heated to a temperature of not less than 350 degrees Fahrenheit nor more than 450 degrees Fahrenheit. This asphalt filler shall not contain pitch nor any part of coal tar. It shall contain at least 98 percent of bitumen soluble in carbon disulphide. It shall remain pliable at all temperatures to which it may be subjected as a street paving filler; it shall be absolutely proof against water and street liquids; it shall firmly adhere to the brick, and be pliable rather than rigid. Care shall be exercised to completely fill all openings around street structures, and the street shall not be used for traffic until the filler is completely set. A top dressing of sand shall be spread immediately after the filler is applied and while it is still soft.

The penetration shall conform to the following:

No. 2 needle, 5 seconds, 100 grams, at 77 degrees Fahrenheit, 25 to 60.

No. 2 needle, 1 minute, 200 grams, at 32 degrees Fahrenheit, not below 25.

No. 2 needle, 5 seconds, 50 grams, at 115 degrees Fahrenheit, not over 110.

A more complete specification for an asphalt filler follows:

The filler shall not contain pitch, coal tar or any product of coal tar, and shall conform strictly to the following specifications:

The filler shall have a specific gravity of not less than 0.980 nor more than 1.010 at 25 degrees Centigrade (77 degrees Fahrenheit).

It shall contain not less than 99.0 percent bitumen soluble in cold carbon disulphide.

The bitumen soluble in cold carbon disulphide shall consist

of 65 percent to 75 percent petrolene soluble in cold petrolic ether (88 degree Baumé).

It shall not contain more than 15 percent "fixed carbon," the method being, that described for coal in the "Journal of the American Chemical Society," 1899, Volume 21, Page 1116.

The penetrations on a Dow machine shall be as follows:

No. 2 needle, 5 seconds, 100 grams, 77 degrees Fahrenheit, 30 to 40.

No. 2 needle, 1 minute, 200 grams, 32 degrees Fahrenheit, not less than 12.

No. 2 needle, 5 seconds, 50 grams, 113 degrees Fahrenheit, not more than 70.

When 20 grams of the material are heated for 5 hours at a temperature of 170 degrees Centigrade (338 degrees Fahrenheit) in a tin box 2½ inches in diameter, it shall not lose over 2 percent by weight.

The filler shall be free from water, and shall not be affected by 24 hours' immersion in 10 percent solution of hydrochloric acid, and shall be impervious to street liquids."

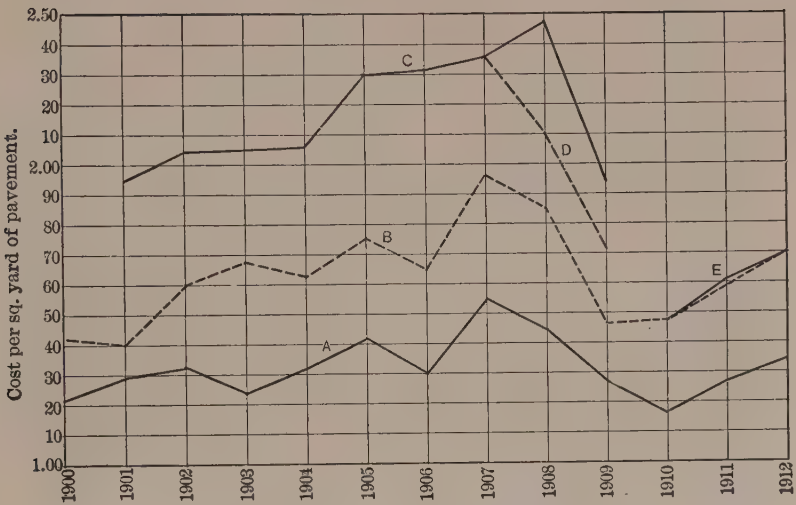
Examples and Cost of Construction. The cost of laying brick in Falconer, N. Y., in 1910, was as follows:

	Cost Cents Per Square Yard
Spreading sand cushion (1½ to 2 inches thick)....	1.58
Laying brick....................................	7.08
Replacing culls, turning, raising low brick, etc.....	1.58
Rolling (5-ton roller)...........................	0.55
Miscellaneous....................................	0.87
Grouting (mixing and applying a 1 to 1 mixture)...	2.74

The cost of a 1 : 2 : 5 gravel concrete with a No. 2½ Foote continuous mixer, after the gravel was on the ground, was 62 cents per cubic yard. This included mixing, placing, spreading and smoothing ready for the sand cushion. Labor was obtained at the following prices: Labor, 23 cents per hour; teams, 50 cents per hour; stone cutters, 50 cents per hour; bricklayers, 30 cents per hour.

The cost of brick pavements on different types of foundations, as laid in Cleveland, under the direction of Robert Hoffman, M. Am. Soc. C. E., is given in Table No. 27:

TABLE No. 27



A ——— = 5 Inch brick on natural sand foundation.
B - - - - = 5 " " " 8 Inch sand or gravel ballast.
C ——— = 5 " " " 6 " concrete.
D - - - - = 4 " " " 6 " "
E ——— = 4 " " " 4 " "

The cost of brick pavements in several American cities in 1911 is shown by the following table:

TABLE No. 28

From *Engineering and Contracting*, April 3, 1912

City	Square Yards	Cost per Sq. Yd.	Foundation		Kind of Filler
			Concrete	Thickness Inches	
Boston, Mass.	34,325	$2.65	1 : 3 : 7	6	Grout
Rochester, N. Y.	134,527	1.99	1 : 3 : 6	6	Grout
Newark, N. J.	121,173	2.03	1 : 3 : 6	6	Grout
Ashtabula, Ohio.	34,870	1.45*	1 : 3 : 7	6	Sand
Circleville, Ohio	50,000	1.38*	1 : 2 : 5	6	Asphalt
Cleveland, Ohio	338,000	1.40*	1 : 3 : 6	4	Grout
Fort Wayne, Ind.	47,603	1.70*	1 : 3 : 6	6	Grout
Kalamazoo, Mich.	15,000	1.84	1 : 8	6	Asphalt
Cedar Rapids, Ia.	50,868	1.59*	. . . . . .	4	Sand
St. Louis, Mo.	218,048	1.65*	1 : 4 : 7	6	Grout
Lincoln, Neb.	46,139	2.10	1 : 3 : 5	5	Asphalt
Independence, Kas.	42,000	1.35*	Macdm	6	Asphalt
Baltimore, Md.	31,202	2.09*	1:3½:7	6	Grout
Columbia, S. C.	3,211	2.19	1 : 3 : 6	5	Pitch
Spokane, Wash.	123,700	2.95	1 : 3 : 6	5	Grout

* Does not include grading.

Maintenance

The maintenance of a brick pavement consists mainly of rectifying any low spots which appear in the surface due to defective bricks or to insufficient foundation. When any heaving occurs due to expansion, if it is of large amount, the pavement may bulge up and necessitate extensive repairs, although some-

FIG. 191. Cleaning Joints Prior to Application of Bituminous Material.

times by cutting out one or two rows of bricks the pavement will settle down again on the sand cushion. The expansion will make the joint where the bricks were removed of small amount, and if this is filled with a bituminous filler, generally no further trouble from expansion will result. If the surface of the pavement becomes somewhat rough, due either to the uneven wear of the brick or to wear at the edges, a bituminous surface may be applied periodically and covered with a layer of screened chips, which will not only serve to protect the brick from further wear but will also make the foothold better and decrease the noise. See Figs. 191, 192, and 193. A bituminous surface has been known to reduce the noise as much as 75 percent.

Eliis R. Dutton describes the application of a bituminous surface on brick paving on a street in Minneapolis, as follows:

FIG. 192. Application of Bituminous Material.

FIG. 193. Bituminous Material on Brick Pavement, Minneapolis.

"One of the principal traffic streets in this city (Nicollet Avenue, from 10th Street to 13th Street) was paved with brick in 1898, using a sand filler, and has shown very little wear considering, except the edges of the brick which have chipped considerably since power flushing was used.

"It was thought the use of an asphalt coating would make the street less noisy and prevent chipping, so consequently one-half of a block was treated in the spring of 1912, and has shown the advantage of so treating old brick paving. The asphalt was applied hot, using about ½ a gallon per square yard. The surface and the joints were thoroughly broomed and dried before the asphalt was applied, and after the application the surface was covered with a thin coating of coarse sand. This experiment has proved so successful that application has been made to treat quite a large yardage in a similar manner, and will probably be done the next season. The asphalt used in this experiment was of the following quality:

Specific gravity at 25 degrees Centigrade ...	0.980
Melting point (American Society of C. E. Test).	117 degrees F.
Penetration No. 2 needle, 100 grams, 5 seconds, 77 degrees Fahrenheit	175
Penetration No. 2 needle, 200 grams, 1 minute, 32 degrees Fahrenheit	60
Loss, 5 hours 325 degrees Fahrenheit.........	2.4 percent.
Bitumen soluble in carbon disulphide.........	99.7 percent.
Organic matter insoluble	0.2 percent.
Ash..................................	0.1 percent.
Bitumen soluble 88 degree Baumé naphtha	75.5 percent.
Fixed carbon	7.8 percent.

"It adheres to the brick very well—does not become excessively soft under severe sun, and has shown no chipping effect from the cold, has reduced the noise, increased the foothold for horses, and greatly improved the appearance of the surface."

Brick pavements can be found that have been in use for twenty years and more that are still in good condition. Where the traffic conditions are not too severe and the pavement has been properly constructed a brick pavement will wear for a long time with practically no expense for maintenance, pro-

vided the expansive forces are not sufficient to disrupt the surface.

A maintenance clause is provided in the 1912 specifications of the Association for Standardizing Paving Specifications, which reads as follows:

"Maintenance. The period of guarantee shall be five years. During the period of guarantee, whenever the surface of a vitrified brick pavement becomes uneven, holding water ¼ inch or more in depth in a distance of 4 feet or less, or when the pavement has settled over trenches filled up previous to the completion of the pavement, then the brick shall be taken up and relaid to proper crown and grade.

"Any brick which may be found soft, unsound, broken, or disintegrated, shall be removed and properly replaced with sound material. All portions of the pavement which may have become rough by reason of the chipping or breaking of the edges of the brick so as to produce joints exceeding ½ inch at a point ¼ inch below the surface of the brick shall be replaced with new materials."

Characteristics

A brick pavement when properly constructed on a concrete foundation is very durable unless the traffic is extremely heavy. If built properly with a bituminous or cement grout filler the surface wears smooth, offers light resistance to traction, is easy to clean, produces no dust, and furnishes a fair foothold to horses. If proper allowances are not made for expansion when cement grout filler is used the pavement is liable to arch itself above the sand cushion and become extremely noisy, which is a decided objection. A bituminous filler prevents the occurrence of such a condition, but unless the proper kind of bituminous filler is used, the edges of the bricks wear and round off under the action of traffic. In some of the smaller cities brick pavement has been successfully used for the business streets, while in some of the largest cities its use is restricted to residential streets. Although in Chapter IV it was stated that a maximum grade of about 5 percent was adopted for brick pavements in the

Borough of the Bronx, New York City, this type of pavement has been used on much steeper grades. In fact, in 1910 there were several instances where brick pavements were constructed on grades of 10 percent and more. In the 1912 highway specifications of the Board of Water Supply of New York City, hillside blocks or blocks having one edge bevelled are required on grades of over 5 percent. If a grout filler is used on steep grades, however, the pavement may become very slippery. A bituminous filler will be found to be of material advantage in such cases.

CHAPTER XIX

CONCRETE PAVEMENTS

Development. The first piece of concrete pavement was laid in 1865, in Inverness, Scotland. This was an experimental section about one hundred and fifty feet long. In 1866 another experiment was tried of about the same length in Edinburgh. Concrete pavements have not been laid in Europe until recently, and then only to a slight extent.

The first concrete pavement in the United States was laid in Bellefontaine, Ohio, in 1893. It was not until 1900, however, that this material was used to any great extent. During 1911 the approximate amount laid in the United States comprised between two and three million square yards. During the past few years it has been demonstrated that the application of a bituminous surface to the pavement makes it more desirable.

The Concrete

Ingredients and Proportioning. The materials used for the aggregate of a concrete pavement are generally broken stone or gravel. Broken stone should be that resulting from the crushing of a hard, tough rock. Preferably the stone should be composed of naturally graded sizes free from dust or dirt. Sometimes, however, the run of the crusher may be used, including the dust, which is acceptable provided that part of the stone below ¼ inch in size is reckoned as sand in making up the proportions. What has been said relative to broken stone applies as well to gravel, since a screened gravel with the fine material eliminated allows a more accurate determination of the correct proportions. Some engineers prefer stone and

others gravel, both being allowed in some specifications. The sand used should be clean, sharp, and coarse, free from loam, clay, and any vegetable or organic matter. The cement should be a first-class Portland cement that will meet the standard specifications of the American Society of Civil Engineers. Care should be taken to use clean water, since water which contains any alkalies or acids will be detrimental to the concrete.

The 1912 specification of the Association for Standardizing Paving Specifications describes the sizes of the aggregates, as follows: "The fine aggregate shall consist of any material of siliceous, granitic or igneous origin, free from mica in excess of 5 percent, and other impurities, and shall be of graded sizes ranging from ¼ inch down to that which shall be retained on a No. 100 Standard Sieve, not more than 20 percent of which will pass a No. 50 Standard Sieve for the base; and from ¼ inch down to that which will be retained on a No. 80 Standard Sieve, not more than 20 percent of which will pass a No. 50 Standard Sieve for the top or wearing surface. The coarse aggregate shall be sound gravel, broken stone or slag having a specific gravity of not less than 2.6. It shall be free from all foreign matter, uniformly graded, and of sizes that will pass a 1-inch screen and be retained on a ¼-inch screen."

The theory of the correct proportioning of concrete has been briefly stated in Chapter VI. The proportions which were given in connection with the construction of concrete foundations are not rich enough in either cement or mortar to make satisfactory concrete which is to be subjected to the abrasive action of traffic. The proportions used for concrete pavements are 1 : 2 : 4 or 1 : 2½ : 4, or, in other words, proportions in which the mortar is from 50 to 60 percent of the aggregate, preferably the latter. Although this condition might be obtained as far as the relation of the mortar and the aggregate is concerned, in a mix of 1 : 3 : 5, it has been found that such a mixture does not produce as satisfactory results as those richer in cement. The 1912 practice of the Illinois Highway Commission was to use a concrete of the proportions 1 : 2 : 3½.

Construction

Subgrade and Foundation. Concrete pavements should only be laid on a well-compacted and well-drained subgrade. If the subgrade is of clay or other heavy soil, it should be replaced with clinker, broken stone, cinders, gravel, or some other suitable material. This surface should be made to conform to the finished surface of the pavement and should be thoroughly rolled with a heavy roller. The formulas for the amount and distribution of crown are given in Chapter IV. In replacing old macadam roads, which have been laid on a telford base, with a concrete pavement, it is possible to dig up the macadam, screen the broken stone, and use it as the aggregate in the concrete. The pavement can then be laid on the telford foundation. It will be remembered that in Chapter VI the subject of foundations was considered from two standpoints, natural and artificial. In this connection it was assumed that the lower course of a macadam road was an artificial foundation for the upper course. A similar condition exists in some concrete pavements which are built in two courses, the upper one being a wearing surface and the lower one the artificial foundation.

Constructing the Pavement. There are a variety of methods of constructing a concrete pavement. Both mixing and grouting methods are employed. In the mixing method the entire thickness of the concrete may be deposited at one time or the pavement may be constructed in two courses. In the grouting method the aggregate is laid, rolled to place, and poured with a cement grout. Steel reinforcement has been used to a slight extent in pavements built by both the mixing and the grouting methods. Another type of construction which has been used is that of molding concrete into small cubes and laying the same as a small block pavement. The practice of painting the concrete surface with a coat of bituminous material has given good results in some instances.

Mixing Methods. In concrete pavements constructed by the mixing method, the concrete is deposited in one or two layers. The two-course pavement seems to be the more popular,

but that better results are obtained by the one-course method is apparently the experience of the engineers of Wayne County, Michigan. Both methods have been tried in this place, the construction of two-course pavements having been abandoned. It is evident that in constructing a two-course pavement there is bound to be a plane of weakness between the two courses. Although it is possible in the two-course method to construct the top with a richer mix, this hardly offsets the advantages derived from having the entire depth of concrete deposited at one time.

The mixing of concrete by hand and by machine has been fully considered in Chapter VI. The general rules which were given in this chapter relative to handling the mixed concrete during construction and its treatment after being laid apply as well to constructing concrete pavements. More attention should be paid to obtaining a smooth and regular surface in constructing concrete pavements than is usually accorded concrete foundations. The use of heavy templates to strike the surface of the concrete and of bridges which span the concrete surface, thus enabling the laborers to work on the surface without standing on it, should be insisted upon. A slightly roughened surface may be obtained by marking the concrete before it sets hard with a grooving tool, by the use of a wood float, or by brooming the surface with a rather stiff broom. It is also more important to protect the surface from too rapid drying out while the concrete is curing, otherwise shrinkage cracks are liable to occur. This is accomplished sometimes by covering the pavement as soon as it has taken its initial set with a canvas which is kept moist for a few hours. The canvas is then removed and the surface is covered with a layer of sand or earth which is kept thoroughly moist for a period of two weeks.

One-Course Method. A one-course pavement is constructed in Wayne County, Michigan, in the following manner: The concrete is mixed in the proportions of 1 : 1½ : 3, and is laid to a compacted depth of between 6 and 7 inches. The ingredients are machine mixed and the resultant concrete is placed

and tamped on a firmly compacted subgrade. The surface is struck off with a plank template similar, but somewhat more elaborate, to the one shown in Fig. 194. Each day's work is finished up to a transverse expansion joint, such joints being constructed every 25 feet along the pavement.

Two-course Method. A common method of constructing a two-course pavement may be described as follows: A layer of

FIG. 194. Testing the Surface of a Cement-Concrete Pavement with a Template.

concrete, which will be 4 inches thick after compaction is placed on the previously prepared subgrade. The proportions of the ingredients in this layer are, of course, variable, but a mixture of 1 : 2½ : 5 may be considered average practice. After this layer has been shaped up and tamped, and before it has begun to set, a wearing course 2 inches in thickness is constructed upon it. The composition of the wearing course is also quite variable. It may consist of a mixture of sand and cement or it may be composed of a mixture of sand, small sized crushed stone and cement. Cement and sand mixed in the proportions of 1 : 2 have been used. Surface mixtures of which broken stone formed a part have been made up of one part cement, one part sand, and one part of ¼- to ½-inch chips. Other features of the con-

struction do not differ essentially from those described under one-course methods.

The Blome concrete pavements are constructed as a two-course pavement, the lower course being from 5 to 6 inches

FIG. 195. Blome Concrete Pavement.

thick and the wearing surface being about 1¾ inches thick. The wearing surface is composed of one part cement to one and

one-half parts of aggregate which is made up of 50 percent of ¼-inch, 30 percent of ⅛-inch, and 20 percent of 1/16-inch granite screenings. The surface, after it is laid, is cut into 4½ by 9-inch blocks by special grooving tools, the grooves being ½ inch wide and ¼ inch deep. See Fig. 195.

The Kieserling pavements in Germany are concrete pavements built in two courses. The surface course is 2 to 2¾ inches thick, and is laid on the foundation course before the latter has set up. The pavement is provided with expansion joints.

Reinforced Pavements. Reinforced concrete pavements are usually constructed by the two-course method. The reinforcement usually consists of woven wire or expanded metal, although a mesh work of small round bars is sometimes used. The reinforcement is universally placed between the base and the wearing surface. This type of pavement may be said to be in an experimental stage. In practically all instances where pavements were constructed by this manner both longitudinal expansion joints at the curbs and transverse expansion joints across the pavement were built at intervals.

Oil Cement Concrete. In order to make the concrete more waterproof, and at the same time to enable it to resist the changes of temperature more effectively, experimental pavements of oil cement concrete have been built. The pavement is constructed in a similar manner to the ordinary concrete pavements by the mixing method except that a fluid residual petroleum is added to the mix in an amount varying from 10 to 18 percent of the weight of the cement. Most of these experiments have been constructed under the direction of the U. S. Office of Public Roads. The addition of oil weakens the strength of the concrete, although it makes the concrete more impervious. The conclusions at the present time are that this method of construction has not shown any advantages which would warrant its adoption.

Expansion Joints. Both longitudinal joints along the curbs and transverse joints should be provided. There is bound to be more or less contraction and expansion of the concrete when sub-

jected to changes of temperature. In cold weather it will contract and in hot weather it will expand. If expansion joints are not present, when the concrete contracts, the tensile strength of the concrete will be exceeded and the pavement will crack; when it expands it will tend to bulge up. Fig. 196 shows a crack in a concrete pavement due to contraction. If the expansion produces forces that are in excess of the compressive strength

Fig. 196. Contraction Crack in a Cement-Concrete Pavement.

of the concrete, the concrete will crush along the crack. The edges of the joints must be protected from the abrasive action of the traffic, and it is obvious that the joints should be filled with a material that will allow some movement between the joints as the pavement expands and contracts.

The width of the longitudinal joints will depend somewhat upon the width of the pavement. They are usually made from ½ to 1½ inches wide and are filled with a bituminous filler. The width of the transverse joints also depends upon the distance between them, and it is considered better practice to construct narrow joints at small intervals apart rather than wide ones far apart. Transverse joints are placed from 15 to 50 feet apart, 25 feet being an average value. It is thought by some engineers that the edges of the transverse joints will not

become so badly worn if they are constructed across the pavement at angles of 60 degrees rather than at 90 degrees, the successive joints not being parallel, but every other joint running in the opposite 60 degree direction.

In constructing concrete roads in Michigan during the last four years several kinds of tranverse expansion joints have been used. The joints have been filled with two thicknesses of three-ply tar paper, with ½-inch boards of southern pine, and with a composition of asphalt, still wax, and pitch. To protect the edges of the joints, angle irons have been built into the surface of the road. The use of angle irons proved so satisfactory in Wayne County, Michigan, that a modified form of angle iron was developed which was used in all of the 1912 pavements constructed of concrete. It consists of two soft steel plates, ½ inch thick and 3 inches wide, which are clamped to a dividing board, the top edge of which is shaped to conform to the crown of the finished road. The plates are provided with means to tie them securely to the concrete base and wearing surface. Between the plates are placed two thicknesses of three-ply asphalted cement felt about ¼ inch thick which extends the entire depth of the concrete.

Grouting Method. Pavements constructed by the grouting method are generally built in two courses. This method of construction has been developed largely by the Hassam Paving Company. A layer of broken stone ranging in size from 1¼ to 2½ inches is placed on the surface and rolled to a thickness of 4 inches so that the top will be 2 inches below the finished grade of the pavement. This course is poured with a grout composed of one part cement and three parts sand. The grout is machine mixed, and is mechanically agitated during the process of pouring, so that there is never any segregation of the cement and sand. The grout mixers are drawn along the road and the grout flows from the machines through a pipe to the surface. During the process of grouting, rolling is continued, and enough grout is poured until the voids in the stone are well filled. On top of this surface a wearing course is constructed which consists of a 2-inch layer of trap rock. This is first rolled and laid

in a similar manner to that of the first course, except that a thin grout composed of one part of cement and two parts of sand is used. The pavement is finished off by brooming and brushing into the surface a thick grout composed of one part cement, one part sand, and one part pea size trap rock. The pavement is thoroughly rolled until the voids are filled in each instance and the surface has become smooth. Fig. 197 shows a section cut from a pavement constructed by this method. The Long

Courtesy of Wm. H. Connel.

FIG. 197. Section of Cement-Concrete Pavement Constructed by the Grouting Method.

Island Motor Parkway is one example of the pavement constructed by the Hassam method except that in this case woven wire reinforcement was used and the stone was laid in one course and grouted from the top. The total depth of pavement is 5 inches, and 2½ inches from the surface is placed the sheet of woven wire reinforcement which extends the full width of the roadway.

Bituminous Surfaces on Concrete. A bituminous surface is readily constructed on the surface of a concrete pavement, provided the proper kind of bituminous material is used. It protects the surface of the concrete from abrasive action of the traffic, offers a better foothold with certain kinds of bituminous ma-

terials, eliminates the dust which is otherwise liable to form on a concrete surface, and does away with the objectionable glare which results when a strong sunlight shines on the concrete. A great deal of this kind of work has been constructed throughout the West, particularly in Ann Arbor, Michigan. The bituminous material used is either a heavy coal tar, a tar-asphalt, or an asphalt cement. It is applied to the surface in the amount of

FIG. 198. Failure of a Bituminous Surface on a Cement-Concrete Pavement.

½ gallon per square yard spread by means of hand methods or by distributing machines. In some cases it is applied by pressure machines in two applications of ¼ gallon each. The bituminous material is sometimes swept in with either a rotary sweeper or with hand brooms. It is then covered with sand or fine stone chips to a depth of ⅜ to ½ an inch. Fig. 198 shows a failure of a bituminous surface on a cement-concrete pavement due to the use of a bituminous material which would not adhere to the concrete.

Concrete Cubes. Since 1909 several trials have been made in New York State of constructing pavements with 2-inch cubes made of concrete. The cubes are moulded either by machine or by floor moulds. With machine moulds it is possible

to turn out on the average twenty-five thousand cubes a day, which is equivalent to 100 square yards. The cubes are dried in racks for twenty-four hours and then seasoned for three months, during which time they are wet down at least twice a day. They are laid by hand on a sand cushion from ¼ to ½ inch thick, the cushion being spread on a layer of broken stone, which has been well compacted. The surface is rolled and then covered with a layer of loamy sand, which is broomed and flushed into the joints. The cubes are supported at the sides by shoulders 4 feet wide which are 2 inches deep close to the cubes and taper off to a feather edge.

Cost Data. The following table shows the average unit prices in 1911 of concrete pavements constructed in various American cities.

TABLE No. 29

From *Engineering and Contracting*, April 3, 1912.

City	Square Yards	Cost per Sq. Yd.	Concrete		Kind of Concrete
			Proportions	Thickness	
Portland, Me.	2,250[1]	$1.41	......	5	Hassam
Portland, Me.	11,238	1.29	1–2½–5	6	Mix.
Lynn, Mass.	21,402[1]	1.70	1–2 –4	6	Mix.
Ann Arbor, Mich.	64,811[1]	......	......	6	Dol'way
Fond du Lac, Wis.	11,043	1.25	1–2½–5	6½	Re-in.
Sioux City, Ia.	100,000	1.20	1–3 –4½	5	Mix.
Kansas City, Mo.	81,000	1.05	1–2½–4½	6	Mix.
Wichita, Kas.	68,486	1.70[2]	......	5	Hassam
Knoxville, Tenn.	3,090	1.88[2]	......	7¼	Granit'd
Spokane, Wash.	56,282	1.95[2]	......	6	Hassam
Spokane, Wash.	36,933	2.40[2]	......	6¾	Granit'd
Portland, Ore.	487,315	1.80[2]	......	6	Hassam

[1] Bituminous top. [2] Does not include grading.

Cost of Mixing. The cost of mixing concrete by different methods has been given in Chapter VI.

Cost of Concrete Cubes. The cost of manufacturing concrete cubes in 1910 per square yard was 42 cents, including the cost of the factory. The cost of laying, including the cost of grouting, was 15.3 cents per square yard.

MAINTENANCE

It is not surprising that the effects of traffic on concrete pavements are very variable, when the variety of mixtures and methods of construction used in constructing this type of pavement in different parts of the country are considered. Uneven places may wear in the surface, as shown in Fig. 199, where the concrete is not uniform in character. Bad spots are very liable

FIG. 199. Uneven Wear of a Cement-Concrete Pavement.

to occur, due to a poor mixture or a segregation of the ingredients when the concrete is placed, unless careful supervision is exercised. Once such a place starts to wear away, it grows in extent very rapidly, the abrasive action of the traffic even attacking and grinding out the good concrete. Such places should, therefore, be immediately repaired, which is best accomplished by cutting them out for a depth of at least 3 inches and refilling with either cement or bituminous concrete, depending primarily upon the traffic conditions. It is useless to try and level them up with the surrounding surface by putting a little mortar in the depression. Places where cracks have formed

should also be given very close attention, since the edges of the cracks and the surface adjacent to them soon wear away. Filling the cracks with a bituminous filler will serve to protect the edges and prevent water from seeping down through the pavement to the foundation. The same care should be taken with the expansion joints to see that they are always filled flush with a bituminous filler. Methods of constructing and maintaining bituminous surfaces have been fully explained in Chapter XII.

Characteristics

A concrete pavement furnishes a smooth surface which is easy to clean and is not productive of much dust, but it is somewhat noisy. Although it affords a fair foothold for horses, it becomes slippery in wet weather, when the fine powder which results from the grinding action of the traffic on the surface forms a sort of slime on the surface. The surface of the concrete can be covered with a coat of bituminous material into which is rolled a layer of stone chips. This treatment will serve to prolong the life of the road, will render it non-slippery practically under all conditions if the proper kind of bituminous material is used, and will make it less noisy.

CHAPTER XX

MISCELLANEOUS ROADS AND PAVEMENTS

The types of roads and pavements which will be considered in this chapter cannot be classified under any of the types previously discussed. Although the methods of construction in some cases are somewhat similar, the materials used are different. The non-availability of good road building material or lack of funds has been responsible in a large measure for the development and use of certain types, while the utilization of waste products has led to the design of others. There are numerous examples of roads and pavements, which come under this head, which have been patented, but never constructed except for some short experimental sections. To attempt to describe all of the different forms would be a stupendous task and beyond the scope of this book. The types considered, therefore, will be those which have been used to more or less extent.

Petrolithic Roads. This type of road is formed by mixing in situ the soil with a bituminous material. It has been constructed mainly in California. The earth is plowed up to a depth of at least 6 inches and is thoroughly pulverized, cultivated, and sprinkled with water. Asphaltic oil may be applied in one to two coats in the amount of 1 gallon per square yard. After a good mix is obtained the surface is recrowned with a road grader and tamped with a sheep's foot roller-tamper. In many cases a layer of broken stone or screened gravel is spread over the roadway, treated with about ½ gallon of asphaltic oil, and is harrowed in. This surface is then rolled and another treatment of oil is applied at the rate of ¼ gallon per square yard. A ½-inch layer of stone screenings or pea-gravel is then spread over the surface and rolled with a smooth-faced roller.

Burnt Clay Roads. Experiments have been tried in a few instances in some of the Southern States to improve the roads by burning the soil of which the roads are composed. In some sections there is no sand and the soil is made up of a very plastic clay. The material is plowed up and is piled over a low crib work of firewood, which is placed directly on the road extending for any desired length and its full width. Alternate layers of wood and earth are built up until a height of about 3 feet is obtained. The length fired at any one time depends upon the number of men available. When the wood burns out the earth will be found to have been burnt to a hard substance and it will lay on the surface ready to be shaped up and compacted. This process of burning also tends to harden the material in the subgrade.

Straw Roads. In the State of Washington clay roads have been improved by shaping and harrowing the road to a smooth surface and then applying a layer of wet wheat straw about 6 inches thick. The straw is cut and mixed with the earth by means of a disc harrow. More straw is used as needed and finally the roadbed is compacted with a steam roller. This construction has resulted in a road surface which, in some instances, has been claimed to have outlasted roads constructed with gravel in the same locality. It is necessary to treat the roads in this manner about twice each year.

Shell Roads. The State of Maryland has built many miles of roads with oyster shells along the eastern shore of Chesapeake Bay. In fact, the shells are about the only available material for surfacing roads in that locality. Where the shells are simply thrown onto the old road bed without previously shaping the latter, the results obtained are not very successful, as the shells soon push down and the mud works up, producing conditions which are not much better than before the road was improved. If the traffic follows in the same track on a shell road, ruts will be quickly formed, and a horse path will be made in the center. If these low places are immediately filled with new shells, it will tend to make the traffic distribute itself over the surface and prevent to a great extent subsequent tracking.

Shell roads, unless watered or treated with some form of dust-palliative or bituminous surface, are liable to be extremely dusty, which is decidedly objectionable not only to those using the road but also to those residing along it.

Good results with this material can be obtained by following the specifications of the Maryland State Roads Commission. These specifications stipulate that the subgrade shall be firm and well rolled as for any metal road. The first course of shells is made either 5 inches at the center and 3 inches at the sides or 5 inches uniform depth. The second course is either 5 inches at the center and 3 at the sides or 3 inches uniform depth. The third course is composed of a clean, sharp sand, no particles larger than ¼ inch, spread just thick enough to cover the second course after the latter has been thoroughly compacted. Raw shells are preferably used. They are spread upon the roadbed with shovels from piles along the road or from a dumping board. They are rolled with an 8-ton roller and are sprinkled lightly with water or bound with sand during the process of rolling until the surface of either course is firmly compacted. Some shell roads in 1911 were constructed with a bituminous surface.

The cost of constructing these roads is given by Major W. W. Crosby, M. Am. Soc. C. E., as follows: "Assuming shells to cost 4 cents per bushel f. o. b. cars at the nearest station; to weigh 57 pounds per bushel of 1¼ cubic feet, and the haul from the station to the road not to average over one mile; then, for a shell macadam surface (on sand) 16 feet wide, 8 inches thick in the center, and 3 inches at the sides after rolling (allowing a reduction of one-half in the thickness by rolling), 62,000 bushels will be required per mile of 9,387 square yards. The cost in detail per square yard will be as follows:

	Per Sq. Yd.
Shells	$0.264
Loading and hauling	.066
Spreading	.020
Sanding, watering and rolling	.070
Total, not including profit to contractor	$0.420

Slag Roads. Blast furnace slags are produced in the manufacture of iron and steel and are very similar in appearance to some of the igneous rocks. In reducing iron ores, the impurities rise to the surface as the iron melts in the furnace and unite with the fluxing material, which is added during the process of refining. This material is drawn off in a molten condition, sometimes cooled in water and at other times cooled in the air. Sometimes it is turned out in a semi-molten condition on the ground and forms large banks. In converting the iron from the blast furnaces into steel by the open-hearth process, more flux is used in the process, which rises to the surface of the molten mass as slag. The slag from the open-hearth process is generally run into moulds and later broken up in order to recover the scrap iron which is always present.

In 1909 an experimental road was constructed in Youngstown, Ohio, under the direction of the Office of Public Roads, in which both blast furnace slag and open-hearth slag were used alone and in combination with other materials. The blast furnace slag was excavated from the slag banks by means of a steam shovel, which served to break the material up fine enough so that it could be screened. About one-third of the material excavated in this manner was between ¾ of an inch and 1½ inches in size. Only a very small percent was over 3½ inches in size. The open-hearth slag was crushed in a rock crusher. In one experiment blast furnace slag was used alone, the road being built in two courses very similar to an ordinary macadam road, water being used in constructing the surface. In another experiment blast furnace slag was used, but the road was constructed with one course. The third experiment was made by constructing a two-course road with blast furnace slag, which was bound together with screenings made from an open-hearth slag. In a fourth experiment the road was constructed in a manner similar to the first, except that 5 percent of powdered quick lime was mixed with the slag screenings. In a fifth experiment, which was built by the same method as the first, a waste sulphite liquor was mixed with water and used to puddle the surface. In the last experiment, the road

was built in two courses, the slag in the top course, which consisted of a mixture of three parts of slag from 1½ inches to ¾ of an inch in diameter to one part of slag varying from ⅜ of an inch to dust, was mixed with about 6 percent of refined coke oven tar. This mixture was laid and rolled and then painted with about ¼ of a gallon of tar per square yard.

Slag composes the mineral aggregate of the Tarmac pavements which are extensively built in the County of Notts, and elsewhere in England. This pavement has been fully described in Chapter XIV.

Clinker Pavements. About 33 percent of the total refuse dealt with in a refuse destructor remains, after burning, as clinker. Many schemes have been tried to utilize clinker commercially. It has been ground and used as sand and has also been broken up and pressed into bricks, paving blocks and slabs, either a cement or bituminous material being added to bind the fine particles together. These bricks, blocks, and slabs have been used in building construction, in road paving, and in sidewalk paving. It is also possible to use clinker as a foundation for bituminous pavements. The experience in Kensington, England, with this kind of blocks has been that they are noiseless, non-porous, unaffected by temperature, furnishing an excellent foothold for horses, and producing no dust.

Blocks manufactured with clinker and a hydraulic cement as a binder, in the proportions of three parts of clinker to one part of cement and one to eight parts of fine dust, have not made a very satisfactory pavement in the Borough of Finsbury, England, when subjected to a heavy traffic. In fact, many square yards of this pavement had to be taken up after it had been down for two years.

Iron Pavements.* "Perhaps the most extended experiment in this country with iron pavements was made in New York about 1865, when iron blocks were laid on Cortlandt Street. The blocks were roughened on the surface by hexagonal projections about 1 inch in size, separated by similar depressions.

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*See *Engineering and Contracting*, September 6, 1911.

The pavement proved a failure as it was rough and noisy, and horses tore off their shoes and slipped and fell frequently. After a short trial the pavement was taken up.

"Impregnated wooden blocks capped with steel were used in 1888 to pave the intersection of two streets in Berlin, Germany. This pavement was removed in 1897 upon the application of the makers. It is stated that at the beginning this pavement

FIG. 200. Cobblestone Pavement.

was fairly durable, but after an existence of eight years its steel capping became so worn under the heavy traffic as to require renewing. These same experimenters had, in 1877, laid an iron pavement on "Unter den Linden" in Berlin. This pavement remained until about 1890, when it was removed at the request of the experimenters.

"An experimental pavement made under the Schreyer patent was laid in 1890 on a sidewalk crossing at an entrance to a railroad freight yard in Columbus, Ohio. This pavement was a combination of iron plates with pockets containing oak blocks. At the end of sixteen months' use it is stated that the blocks showed a wear of but ¼ of an inch.

"These are about the only extended experiments with iron

pavements concerning which information is available. Of late years few attempts have been made to use iron as a paving material. In fact, but two patents for pavements in which iron is the prime factor have been taken out since January 1, 1900.

"The patents which have been granted for iron pavements may be divided roughly into four classes:

(1) Pavements composed of circular or rectangular frames fitted with means for interlocking.

(2) Interlocking iron plates.

(3) Combination pavements composed of iron pockets containing gravel, wood blocks, or bituminous materials.

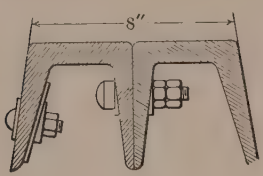
(4) Iron paving blocks."

Cobblestone Pavements. Cobblestone pavements are now rarely laid except on unimportant streets or alleys or as a substitute until a better pavement can be obtained. Hard, durable stones ranging from 5 to 10 inches in depth and from 4 to 8 inches across the head are used. The stones are laid on a bed of loamy sand about 6 inches thick, and are set compactly together so as to break joints as much as possible. The surface is then covered with sand, which is swept into the joints, after which the

Fig. 201. Stone Trackway in Glasgow, Scotland.

stones are tamped with a rammer weighing about 50 pounds. When there is no further settlement of the stone, the surface is covered with a layer of sand about ½ an inch in depth. A cobblestone pavement, if subjected to a heavy traffic, soon gets out of shape. Fig. 200 shows a surface which is typical of this pavement. The cost of this type of pavement is from 60 to 70 cents per square yard.

Trackways. Trackways have been built, both in this country and abroad, of stone slabs, brick, concrete blocks, steel shapes, and other materials. Stone trackways were used on one of the old toll roads in New York State as early as 1831. Limestone slabs, 24 inches wide and 4 inches thick, were laid with such a gauge as would ac-



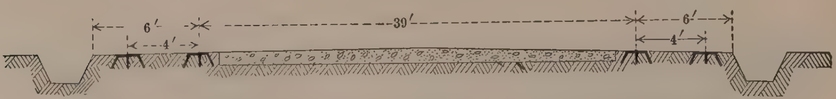
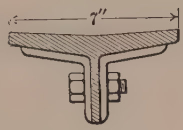


Fig. 202. Trackway Constructed Between Grao and Valencia, Spain.

Fig. 203. Trackway on a Street in Valencia, Spain.

commodate the vehicles, and the space between them was paved with cobblestone. In some cities of England and Scotland trackways of rectangular stone blocks, averaging 12 inches wide, 6 inches thick, and of varying lengths, have been used for many years on steep hills or where the traffic is exceptionally heavy. Fig. 201 shows one of these trackways on a street in Glasgow. A trackway composed of concrete blocks approximately 12 inches wide, 8 inches thick, and 24 inches long, constructed in a macadam surface near Orlando, Florida, proved to be very satisfactory for automobiles. In Switzerland, granite trackways, made of slabs 2 feet wide, 1 foot thick, spaced 4 feet apart on centers, are used in several different cities. Only a very few experiments with iron trackways have been

tried in the United States, and probably none are in existence to-day. One of the most famous iron trackways is that one which runs between Grao and Valencia in Spain. It has been in use since 1892, and has shown only slight signs of wear up to the present. The steel track was made up of steel sections as shown in Fig. 202. Fig. 203 shows a cross-section of a steel trackway which has been recently laid in one of the streets of Valencia as an experiment. Fig. 204 shows a



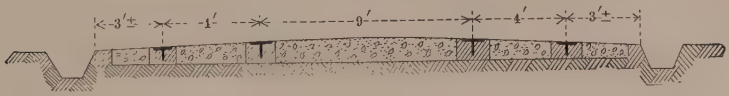


FIG. 204. Proposed Trackway from Grao to Castellon, Spain.

trackway which has been proposed for a road between Grao and Castellon in the same country. At the Second International Road Congress held in Brussels in 1910, it was reported that in the Province of Hanover, Germany, there were 28 miles of iron trackways in existence and 4 miles under construction, which were giving very satisfactory results. It was the conclusion of this Congress, nevertheless, that the use of trackways in paved roads, except in exceptional cases, could only be considered an expedient.

CHAPTER XXI

STREET CLEANING AND SNOW REMOVAL

Street Cleaning

Local conditions, together with grade, character, and amount of traffic and the type of surface influence to a considerable extent the method selected to keep the street as dustless and clean as possible. When the traffic is composed largely of automobiles a bituminous surface of certain asphaltic materials will tend to absorb the dust to a large extent with the result that the thoroughfare will be practically dustless. On narrow and well built up streets which take a heavy horse-drawn vehicle traffic, sweeping and water flushing is usually necessary, while on the open boulevards the removal of the dung of animals may be sufficient on certain kinds of surface. On the more heavily traveled pavements of asphalt, concrete, brick, stone block and wood, a combined watering or washing and sweeping will give the best result.

Hand Cleaning. Hand cleaning is either done by gangs or patrols. In the first-named method the pavement is cleaned at frequent intervals, while in the latter case each patrolman has a certain district to clean each day, each man having a push broom, shovel, and can carrier in which to collect the refuse. The principal disadvantage of the gang method is that the streets are in an objectionable condition for the greater part of the interval between consecutive cleaning operations. In the patrol system the material is collected in cans or bags and placed to one side or is swept into heaps at the side of the street, each awaiting the arrival of wagons to carry the refuse to the dumping grounds. In almost every city of size in Europe may be found a patrol system well organized and highly efficient, but in this country the poor supervision and general indifference

given the matter are usually responsible for the lax and shiftless systems encountered in so many of our smaller cities. Hand sweeping is entirely confined to the day time.

Machine Sweeping. Horse sweepers are employed in many cases, the work being done generally at night. Such sweeping should always be preceeded by sprinkling to ensure the laying of the dust. There are numerous combined sweepers and sprinklers, both horse drawn and motor propelled, in use in Europe. This treatment alone is excellent on streets subjected to light traffic, but on the heavier traveled thoroughfares it should be supplemented by hand sweeping during the day. A pavement in good repair is essential for best results with a mechanical sweeper. For cleaning asphalt pavements a sprinkler combined with a rotary scrubber is employed with good results.

Hose Flushing. Hose flushing is employed to a considerable extent in Europe and to a limited extent in this country. The material is carried in suspension to the sewer through the nearest catch basin. This treatment is particularly efficient in removing all fine dirt, but it necessitates the preliminary removal of all coarse material, which might in time clog the ordinary sewer pipe. Flushing is accomplished by applying a stream of water to the surface with a broad, sweeping motion. In addition the pavement is scrubbed with rubber squeegees worked by hand to remove any adhering solid matter. Various types of flushing machines are used which throw the water in broad, fan-shaped sprays against the surface of the pavement, thus washing the detritus to the gutters.

A good cleaning system might be summarized thus: First, machine sweeping at night to remove all coarse matter, which should be preceded by sprinkling to lay the dust; second, flushing to clean off the fine material; third, supplemental day hand sweeping to pick up the coarse litter, the latter being essential on busy thoroughfares. On bituminous and other pavements subjected primarily to motor car and light horse-drawn vehicle traffic, patrol hand sweeping will generally be sufficient without mechanical sweeping. Periodical watering of pavements

to lay the dust during the day is fundamentally wrong since the fine dust which necessitates sprinkling should have been removed.

Methods and Cost Data. A brief description of methods of street cleaning employed in various countries will now be given, together with cost data.

Great Britain. In London the street cleaning is done under the direction of the Engineering Bureau of the Public Health Department. Each night the streets of the city are washed over by hose flushing or by water carts, the work being done between the hours of 8 P.M. and 6 A.M. Men broom or squeegee the surface during the process of flushing. During the day time the streets are swept by hand with brooms in dry weather and squeegeed in wet weather. The streets are also patrolled by so-called orderly boys who pick up all litter and sweep up horse droppings.

T. H. Yabbicom, in a paper presented before the Second International Road Congress, held in Brussels in 1910, described the methods of street cleaning typical of twenty great towns of England, including five of the boroughs of the City of London, and fifteen towns outside of the great metropolis, including such places as Liverpool, Manchester, Edinburgh, and Belfast. He found that 32 percent of the streets in sixteen of these towns are paved with stone setts, 3 percent with wood paving, 5 percent with various materials, including asphalt, and 60 percent with macadam. Records from twenty towns showed that horse drawn sweepers are used in fourteen to cleanse the macadam roads. The principal streets in all of the towns are cleansed at least once each day, and more frequently when necessary. The second-class streets are swept three times a week, while the suburban roads are cleaned in some places only once a week. The streets are swept during the night in eight towns, during the day in seven others, and in the other five, both day and night. Street orderlies, mostly boys, are employed during the day time in each town to pick up the litter and sweep up horse droppings. The refuse gathered by the street orderlies is placed in small hand carts and dumped at some depot or it is placed in bins which are constructed above or below the level of the

pavement. Street sweeping is generally preceded by sprinkling when the streets are dry. Although various types of combined rotary sweepers and water sprinklers in the same machine have been tried by eight out of the twenty towns, only two found that the machines worked with any degree of success. Various types of water carts are used in the different towns, some having a capacity of about 450 gallons mounted on four wheels, while others hold from 200 to 300 gallons and are mounted on two wheels. The tanks are generally rectangular in shape. Motor vehicles as well as those drawn by horses are used for watering in Westminster and Cardiff.

France. In Paris the street cleaning is done under the direction of the Department of Public Works. The streets are swept with horse drawn sweepers and the sidewalks by hand brooms, the work being done between 4 and 7 A.M. The streets are always watered before sweeping. The refuse is either swept to the gutters or collected and placed in pits and removed by carts. These methods are combined with gutter flushing during the day. When the gutters are flushed the street is swept with hand brooms, and the material, as it is swept into the gutters, is carried away by the water to the sewers. Rotary brooms on two wheels are used for machine sweeping. Horse drawn squeegees are also employed for cleaning asphalt and wood pavements. The quantity of water required in cleaning operations varies from 0.11 to 0.22 of a gallon per square yard for asphalt; 0.32 to 0.44 of a gallon for wood, and 0.44 to 0.66 of a gallon for a stone pavement. Motor driven water carts and sweepers have been experimented with to some extent. The main part of the sprinkling, however, is accomplished by the hand drawn carts of a capacity of from 40 to 50 gallons or with horse drawn carts which hold from 250 to 300 gallons. The average cost in 1906 of cleaning the pavements of the city of Paris is given by Soper as 5.3 cents per square yard per year.

Germany. In Berlin a special committee of the City Council has charge of the street cleaning operations. Rotary machine brooms are used to sweep the streets at night, beginning at 11.30 P.M. During the day the streets are sprinkled by motor

wagons and horse drawn carts. Watering is immediately followed by cleaning with horse drawn rotary squeegees. In those places where the water is not removed by the horse drawn squeegees, the pavements are cleaned by men or boys with hand brooms or squeegees. Although several machines which dampen, sweep, and take up the material have been used, they have not proved to be very satisfactory. Several Hentschel flushing wagons are owned by the city, and, although only six of the twenty-eight are operated by motors, it is intended to equip the remainder with electric motors in the future.

Austria. Horse drawn sweeping machines are used to sweep the streets, which are previously watered by motor driven sprinklers. The refuse is gathered together by gangs of men following the sweepers, and is later removed in carts. The work is carried on each night between the hours of 10 P.M. and 6 A.M. The streets surfaced with asphalt are watered and squeegeed in the morning between 5 and 8 o'clock.

United States. In the City of New York the cleaning is done under the direction of the Department of Street Cleaning. The streets are cleaned mainly by hand sweeping by laborers working under the patrol system. Each laborer is supplied with a can carrier, a push broom, and short handled broom, a long handled scraper and a dust pan. Each patrolman has a certain definite area that he must keep clean, the length varying from a few hundred feet to one mile, depending upon the type of pavement and the traffic. Most of the hand sweeping is accomplished in the day time without previous sprinkling. Horse drawn sweepers are employed to a small extent, the work being done mostly at night. During the day time in the summer months a few streets of the city in the crowded districts are flushed either by hose or by machine. A commission which was appointed by Mayor McClellan, in 1907, to make a report on the street cleaning and the disposal of the city waste included in its report several tables of the estimated costs of cleaning streets by different methods. These tables are reproduced below.

Estimated Cost of Machine Sweeping

COST OF ONE OUTFIT (new)

1 sweeping machine	$275.00
½ of 1 horse power sprinkling wagon	104.00
12 hand brooms, at 65 cents	7.80
6 shovels, at 75 cents	4.50
2 horses for sweeper	600.00
½-horse for sprinkler	150.00
2½ sets of harness, at $25	62.50
	$1,203.80

ANNUAL CHARGES

Interest on this outfit, at 4 percent.	$48.15	
Repairs and depreciation on tools, at 20 percent	90.76	
Depreciation on horses, at 15 percent	112.50	
Total annual charges	$251.41	
or for 310 days, per day		$0.81

OPERATING EXPENSES PER DAY

Maintenance of 2½ horses, at $1.35	$ 3.375	
Rent, storage of sweeper	.20	
Wages, 1 sweeper-driver	2.19	
Wages, ½ of sprinkler-driver	1.095	
Wages, 6 gutter sweepers, at $2.19	13.14	
15,000 gals. of water used for sprinkling at $90 per 1,000,000	1.35	
		21.35
Grand total cost per day		$22.16

The above outfit will sweep once about 70,000 square yards of street in one day of eight hours, and the cost per thousand yards will be $0.317. The cost of loading the sweepings into carts and the cost of administration are omitted, because these items may be considered as costing about the same, whatever method of cleaning is employed.

Estimated Cost of Hand Sweeping

COST OF ONE OUTFIT

1 hand cart	$10.00
5 cans for sweepings, at $2.50	12.50
4 hand brooms, at 65 cents	2.60
1 shovel	.75
2 steel scrapers, at $2	4.00
	$29.85

ANNUAL CHARGES

Interest on outfit, at 4 percent	$ 1.19	
Repairs and depreciation, at 60 percent	17.91	
Total annual charges	$19.10	
or, for 310 days, per day		0.062

COST OF OPERATION PER DAY

1 sweeper	2.19
Total cost per day	$2.252

One such sweeper will clean satisfactorily 8,000 square yards of asphalt pavement per day, and the cost per 1,000 square yards will be $0.281.

Estimated Cost of Hand Washing with Improved Nozzle

COST OF ONE OUTFIT

100 ft. of 2-in. hose, at 80 cents	$80.00
One 1-inch nozzle, special	12.50
6 brooms, at 65 cents	3.90
	$96.40

ANNUAL CHARGES

Interest on outfit, at 4 percent	$ 3.86	
Repairs and depreciation, at 150 percent	144.60	
Total annual charges	$148.46	
or, for 310 days, per day		$0.479

OPERATING EXPENSES PER DAY

2 sweepers, at $2.19	$4.38	
57,600 gallons of water at $90 per 1,000,000	5.184	9.564
Total cost per day		$10.043

If we assume that the work would be done at the rate of 5,000 square yards per hour, or 40,000 square yards per day, the cost per 1,000 square yards would be $0.251.

ESTIMATED COST OF CLEANING BY FLUSHING MACHINES

COST OF ONE OUTFIT

1 flushing machine		$1,000.00
6 hand brooms, at 65 cents		3.90
3 shovels, at 75 cents		2.25
2 horses, at $300		600.00
2 sets of harness, at $25		50.00
		$1,656.15
ANNUAL CHARGES		
Interest on outfit, at 4 percent	$ 66.25	
Repairs and depreciation on tools, at 14 percent	147.86	
Depreciation on horses, at 15 percent	90.00	
Total annual charges	$304.11	
or, for 310 days, per day		0.982
OPERATING EXPENSES PER DAY		
1 driver	$2.19	
½-day of one helper	1.09	
Maintenance of 2 horses, at $1.35	2.70	
4 laborers collecting dirt in gutters, at $2	8.00	
Rent, storage of machine	.20	
Value of water used, 56,000 gals, at $90 per 1,000,000	5.04	
		19.220
Total cost per day		$20.202

One machine will clean a total of 28,000 square yards and the cost per 1,000 square yards will be $0.721.

In Washington, D. C., all of the streets in the central portion of the city are cleaned by hand patrol each day with the exception of Sundays and holidays. In this work each street is actually swept over about three times. The streets outside

of the section which is cleaned by hand patrol, are sprinkled and swept by machine sweepers about three times a week. Alleys are cleaned about once a week, and unpaved streets are cleaned about once every ten days. The work is under the supervision of the Division of Street Cleaning, which is a part of the engineering department of the district. The streets in the central portion of the city, besides being cleaned by hand patrol, are sprinkled and gone over with a rotary squeegee about three times in two weeks. The streets in the hand patrol section are paved largely with sheet asphalt and asphalt block. The streets which are paved with stone block or cobble are cleaned with pressure flushing machines. The cost of hand patrol work, including overhead charges and the removal of the sweepings was, in 1910 and 1911, $0.1753 per 1,000 square yards. The cost of street flushing was $0.3157 per 1,000 square yards. The cost of machine flushing, alley cleaning, etc., was $0.2275 per 1,000 square yards, including the removal of the refuse. The cost of cleaning unpaved streets, including the removal of the debris, was $0.4231 per 1,000 square yards.

In Boston the business streets are swept by machine sweepers each day, shortly after midnight. The streets are then flushed with flushing machines. During the day time the streets are kept clean by hand patrol. The amount of water used for street flushing was 0.321 gallons per square yard of pavement. The cost of flushing in 1911, not including the cost of water, was $0.365 per 1,000 square yards. The cost per 1,000 square yards for machine sweeping was $0.489. The cost of hand patrol work is given in terms of cost per cubic yard and cost per barrel of débris removed instead of the cost per square yard. The average cost per cubic yard in several districts was $3.40, while the average cost per barrel was $0.441.

Snow Removal

The methods used in dealing with snow on highways are influenced to a great extent by climatic conditions. There are localities in our northern climates or in high altitudes where

the snowfall is of large amount and the cold is so intense and constant that the snow melts but little until the spring. In such places it is not so much a question of removing the snow as it is of making the highways passable, moving no more snow than is necessary to accomplish this purpose. The drifts are cut through or smoothed out and the whole road is compacted by a light roller, or, in other words, a snow road surface is made and maintained through the winter months. In practically all of the large cities of the United States and many of those of Europe, it is the practice to remove the snow from the business districts at least, as soon as possible. A heavy snowfall will not only cause extreme inconvenience to the public, but it may seriously impede and hinder the traffic and business of a city.

Removal by Plows. As a general rule the streets on which car tracks are located are cleaned first. The traction companies naturally try to keep the cars moving and the snow no sooner begins to fly before special cars, equipped with brushes or plows, are sent out over the different lines to clear the tracks. It is this principle of starting work of removal before the snow attains any depth that makes their efforts so uniformly successful. It is a rare occurrence for the cars to be blocked for any length of time except in the most severe storms. The work done by the traction companies is of the utmost assistance to vehicle traffic, and in many of our American cities the cleared trackway is about the only place in the entire street width where it is possible for traffic to make any progress at all. In Vienna the tramways are controlled by the municipality, and it is the practice there to plow the snow from the roadway towards the gutter at the same time it is removed from the trackway. This is accomplished by coupling two plows to the car. The plows consist of platforms mounted on four wheels underneath which are a series of horizontal rods to which are attached vertical blades capable of being raised or lowered. When the plows are used in pairs one is drawn along to one side and just behind the other in such a way as to clear two widths at one passage. These plows can be run at a speed of about seven miles per hour.

The car itself is fitted with a plow which clears the snow from the track. This method works satisfactorily for a small depth of snow. When a heavy fall is to be removed it is done by setting the blades so as to take off the upper layer of snow, the remainder being removed on a second trip. In storms where the fall is extremely heavy and fast, cars equipped with heavy plow blades are used to clear the track.

Ordinary V-shaped plows are used extensively to clear a path for vehicles in roads and streets not occupied by car tracks. Rotary sweepers can be successfully used to remove light falls of snow. In Paris these sweepers are used for snowfalls from ½ to 1 inch in thickness. Rotary brushes are also used by the traction companies in clearing snow from the tracks, in which case the brush is generally run by a motor. One objection to horse-drawn sweepers for snow removal is that the speed of the brush is not fast enough to prevent the bristles from becoming choked up with snow so as to perform no sweeping action at all. Road scrapers can be used sometimes very advantageously in doing this work.

In cleaning the roadways by the methods outlined, the snow is pushed towards the gutters. The snow from the sidewalks is also moved to the same point with the result that a drift is formed. These drifts will assume large proportions when a heavy snowfall occurs and will not only restrict the limit of traveled way, but also hinder the surface drainage. When the snow starts to melt the water will back up into the cellars of the abutting property unless considerable care is taken to keep a passage clear for the water to flow to the catch-basins or other inlets. The removal of the snow which has been thus gathered is accomplished in several ways. In light storms the drifts are gathered into large separate piles which are later removed by carts. When the drifts are large they are removed by carts without previous piling. The snow is taken by the carts to some natural waterway, or is dumped on vacant lots or discharged through manholes into the sewers under certain conditions. Although various machines have been devised for the purpose of melting the snow gathered together in this man-

ner, none of them have been successful as yet, at least from an economical standpoint.

A great deal of attention is given in European cities to planning a scheme of organization early in the season to perform the work of removing the snow, so that the work may be accomplished without any unnecessary delays. Many times district depots are established with a full equipment of tools and implements sufficient to do the work in that district. Laborers are hired with the understanding that when the snow commences to fall they are to report to that particular station for work. The work can be attacked in an intelligent manner in this way, as the superintendent of the district knows beforehand just what means he will have at hand to carry it out.

Removal by Use of Salt. The use of salt in connection with snow removal is objected to by some on account of the intense cold produced and its injurious effects on shoe leather and horses' hoofs. In Paris, however, as soon as the snowfall occurs, the workmen commence at once to salt the roadways, spreading the salt with shovels. The salt produces a thawing action after the traffic has mixed it with the snow. The mixture of snow and salt is then swept to the gutters by sweeping machines, after which it is flushed into the sewers by turning on the water from hydrants. A rock salt is used in Paris, selected mainly from the standpoint of its low cost. For a snowfall of about 1 inch, 0.18 of a pound of salt is used per square yard. The specification for the salt is as follows: the largest diameter of the grains of salt must not exceed 0.12 of an inch; the proportion of fine grains passing a sieve number 25 shall not exceed 40 percent; the salt shall not be adulterated.

Removal by Flushing. The practice of flushing is quite common in many European cities. Flushing is not carried on when the temperature is below the freezing point on account of the danger of ice forming in the sewers.

Cost Data. In many places, both in Europe and in this country, it is customary to let out the work of snow removal by contract. The method of paying for contract work varies

in different communities. In some places the area of the roadway surface is determined and a price agreed upon for each inch of thickness of snow, including the cost of sweeping and transporting to the dumping place. Another method is to obtain a price per cubic yard of snow swept and heaped along the road and a separate price for the transportation. Sometimes an overhaul clause is included in the contracts. The special committee appointed by Mayor McClellan in 1907 to report on the methods of street cleaning of New York City recommended that a contract price per cubic yard be determined upon, the cubic yardage to be estimated by figuring the area of street from house line to house line and a depth which would be 30 percent of the depth of fall as recorded by the U. S. Weather Bureau.

The cost of snow removal was 55 cents per cubic yard in Boston in 1906 and 1907. The cost of snow removal in New York City from 1903 to 1908 is shown by the following table.

TABLE No. 30.

From *Engineering and Contracting*, Sept. 6, 1911.

Winter	Total Snowfall in U. S.	Snowfall Removed, Inches	Elapsed Working Time, Days	Amt. Removed, Cu. Yds.	Cost Cu. Yds.
1903–1904	33.0	30.6	104	2,325,524	$0.2425
1904–1905	55.1	54.3	89	10,104,702	0.2030
1905–1906	22.1	21.4	70	3,588,934	0.1500
1906–1907	52.4	43.7	53	10,422,052	0.1650
1907–1908	32.2	15.9	...	811,484	0.327

Mechanical Appliances

A brief description of some of the various tools and machines used in accomplishing the work of street cleaning follows.

Push Brooms. The ordinary push broom is universally used in street-cleaning operations. In this country the brooms are about 16 inches wide. The head is filled with split bamboo, rattan, hickory, or steel wire. One edge of the broom

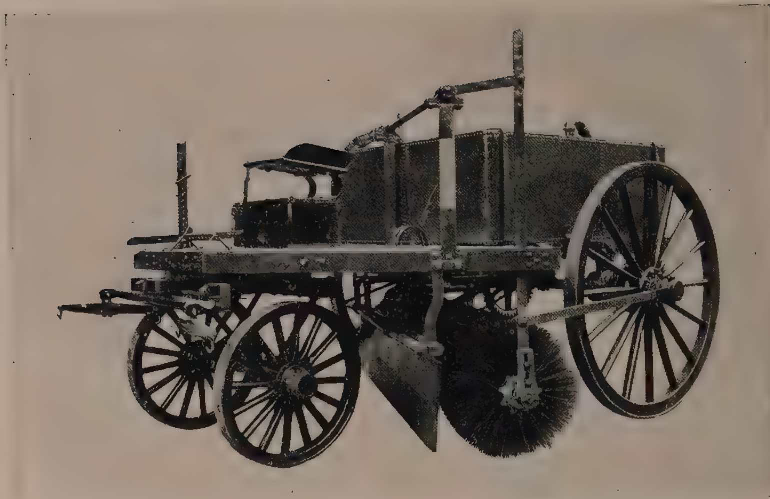
head is sometimes fitted with a steel scraper. These brooms are used for heavy sweeping. For lighter and more thorough sweeping the head is filled with bass wood, which is more pliable than some of the other forms of filling. In Europe hand brooms made out of birch or other twigs are still used to some extent for light sweeping. Push brooms, similar to those employed in the United States, are also in general use. In one

Courtesy of Charles Hvass and Company.

FIG. 205. Rotary Sweeper.

form of push broom the filling is enclosed by a wooden clamp that can be moved up and down so as to make the filling as stiff as desired. The average price of hand push brooms is about $6 per dozen. A small rotary sweeper on three wheels, pushed by hand, has been used in Europe. A man with this machine can sweep three times as much area as he can with the ordinary push broom.

SWEEPING MACHINES. Rotary horse-drawn sweepers, see Figs. 205, 206, and 207, are made to sweep widths varying from 6 to 9 feet. By means of levers operated by the driver the broom can be made to engage the road surface with either a light or heavy pressure. The brooms are filled with rattan, split



Courtesy of Charles Hvass and Company.

FIG. 206. Rotary Sweeper and Sprinkler.

FIG. 207. French Rotary Sweeper and Sprinkler.

bamboo, or hickory. A two-horse rotary sweeper with steel frame will cost about $400. A one-horse sweeper with wooden frame will cost about $250.

Motor-truck sweepers have been used in Europe for several years. In France it was found that although they could accomplish four times as much work with this type of machine as with horse-drawn types and with a lower operating cost per square yard, yet the method was too costly on account of the charges

FIG. 208. English Motor Truck Sprinkler.

for sinking funds and repairs. By strengthening the working parts this charge could, without doubt, be considerably reduced.

Several types of pick-up sweepers have been designed and used. One of the most successful is pushed by hand and consists of a rotary brush geared to the wheels. The brush is covered in with a hood and operates on the carpet-sweeper principle, throwing the sweepings into a pan which is a part of the machine. The sweeper will clean at one passage a strip 30 inches wide. The cost of this sweeper is about $75. This same machine is fitted to a one-horse four-wheel truck which carries two cans, the dust pan when filled being dumped into the latter. The broom in this machine is 54 inches wide. This machine costs about $250.

Motor pick-up sweepers, which have been used in Europe, as a rule have been found to give satisfactory results, although the cost of operation can not be accurately estimated at the present time. These machines are generally provided with a water tank which sprays the dust just before it is picked up.

Bags and Cans. Sweepings may be collected in galvanized iron cans or in bags which are later removed by wagons. Cans

Courtesy of Charles Hvass and Company.

Fig. 209. Rotary Squeegee.

of this sort cost from $2.50 to $3.50 each. Bags cost 5 or 6 cents each. A two-wheel truck for carrying a bag to hold the sweepings costs about $12. Cans for holding sweepings are fixed to a wheel truck in such a manner that they can be attached and detached from the truck by a very simple operation. A dust pan is also attached into which the sweepings are broomed. The pan can be raised by a lever and dumped into the can. The truck is pushed by hand. This machine complete costs about $25.

Courtesy of the Kindling Machinery Company.

FIG. 210. Rotary Squeegee.

Sprinkling Machines. Horse-drawn sprinklers have been previously described in Chapter IX.

Motor-truck sprinklers, as shown in Fig. 208, some of which have the sprinkling attachment on the front of the machine instead of in the rear, are used in Europe. The iron tanks of the European sprinklers are rectangular rather than cylindrical in shape as in this country.

Squeegees and Scrubbers. For the purpose of cleaning asphalt and other smooth pavements, scraping and flushing are resorted to and may be done by hand and squeegee, or by a rotary scrubber. The squeegees are made of wood or metal with a rubber edge in widths varying from 12 to 20 inches. They cost about $1 each. The rotary scrubbers, see Figs. 209 and 210, are built on somewhat the same principle as the rotary sweeper and are attached to a cylindrical sprinkling wagon. As the water falls upon the surface it is pushed towards the gutter by the scrubber. This machine complete costs about $1,250. Hand scrapers for use in cleaning asphalt pavements cost from $2 to $3 each, depending upon the size. They are made about 36 inches wide.

CHAPTER XXII

CAR TRACKS

It was pointed out in Chapter IV that, from the standpoint of the highway, the location of car tracks within the limits of the carriageway is accompanied by several disadvantages. The progress and development of communities, however, are dependent to a large extent upon the systems of transportation between them and the surrounding districts. Street railways and motorbuses are the two systems which must be considered in designing the highways. Although it is reasonable to expect that in the future motorbuses may replace surface railways in many instances, it is extremely doubtful if in the near future their use will ever become so common that transportation by electric traction railways on the roads and streets will be entirely eliminated. The problem, then, is to construct the railways so that all of the advantages can be enjoyed and all of the disadvantages will be reduced to a minimum. This will involve a consideration of the location of the tracks and details of track construction.

Location. There are several advantages in having the car tracks located on a part of the highway which is inaccessible to other traffic. This arrangement does not interfere with the convenience of those entering and leaving the cars and has the added advantage that the cars can be operated at higher speeds without danger to other traffic. The work incident to the maintenance of the tracks can be carried on without disturbing the surfacing of the carriageway, and obviously since the tracks are without the carriageway the wear of the latter is not affected by their presence. From the standpoint of the traction companies several advantages may be noted. The cost of the original construction is generally much less than where the tracks are located within the carriageway due to the fact that the

special methods of construction necessitated in this last instance are not required. The expenses of maintenance are also smaller than where the tracks are so situated that they can be occupied by all kinds of traffic.

The arrangement, which is above described, may be accomplished sometimes in cases of wide residential streets or boulevards, where the tracks may be located either at the sides or in the center of the highway. There are very few instances in cities of this country, however, where this arrangement is carried out except in the case of boulevards. The common arrangement is to have the car tracks located within the carriageway, either in the center or at the sides, the tracks being made flush with the adjoining pavement so as to offer as little obstruction as possible to the other traffic on the highway. Whether the tracks should be located in the center or at the sides is dependent, of course, upon the local conditions, but primarily depends upon the width of the carriageway. The same general principles govern, regardless of whether the location of tracks in a street or a road is being considered. In Chapter IV the New York City ordinance was quoted as requiring a minimum width of roadway of 30 feet for streets in which there is a single track railroad and 40 feet for those in which there is a double track railroad.

While local conditions determine in each case what the best location is, the following information will be of assistance. The width out to out of cars varies from 8 feet to 9 feet 1 inch. The clearance allowed between passing cars on a double track is variable, depending somewhat upon the speed. It is generally a minimum of 5 inches and may be as much as 2 feet on very wide streets, where there is plenty of room. The track gauge in this country is almost universally made about 4 feet 8½ inches. In Europe there are several instances of railways with much narrower gauges, sometimes being as small as 2 feet 6 inches. If a standard gauge is used and a minimum clearance, the distance center to center of tracks for the widest cars will be 9 feet 6 inches and the total width out to out of cars on the tracks will be practically 14 feet.

Track Construction. Experience has shown that the maintenance of a road surface adjacent to a car track is more costly than it would be if the track was not present. It is the opinion of some engineers that the greatest enemy to a railway is not the cars or the vehicular traffic, but water, and from its effects is attributable 90 percent of the maintenance charges. The water seeping down by the rail, particularly at the joints, softens up the underlying soil with the result that the track pumps and the adjacent pavement are soon disintegrated. Sometimes the surface of the rail head as it comes from the rolls is more or less uneven and wavy. The treads of car wheels soon get worn uneven, and this together with the unevenness of the rails, produces vibrations which are very injurious to the adjoining pavements. Some lateral thrusts are also developed as the cars proceed along the tracks. Sheet asphalt and other

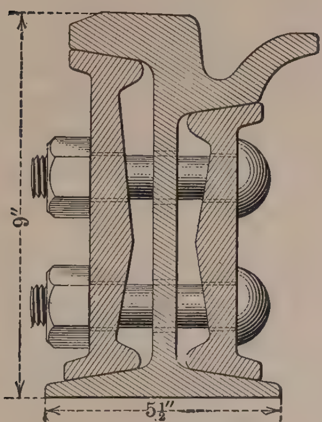


Fig. 211. Grooved Rail.

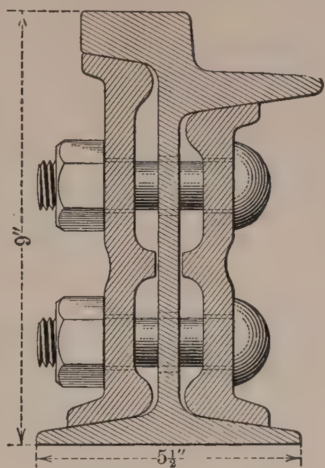


Fig. 212. Stepped Rail.

types of bituminous pavements are particularly susceptible to a very small movement of the rail both laterally and vertically.

Rails. It is interesting to follow the development of the present types of rails used in street railway construction. Among

the earliest types was a flat stepped head which was spiked to a wooden stringer, the stringers resting on wooden cross ties. The traction companies in those times were not obliged to build their tracks so as to obstruct the other traffic on the carriageway as little as possible. In fact, one type of rail was developed for use in New York City, which was designed with the intent of being so objectionable that the vehicles would keep off of the car tracks. This, like the first rail described, was a rail head which was spiked to a wooden stringer. Instead of being a stepped head, however, with one side flush with the pavement, the rail head projected above the surface of the surrounding pavement in the form of an inverted U, the car wheels having a center groove. The railway companies soon appreciated that more permanent construction was necessary, and many types of rails were developed in which the head could be removed when worn and replaced with a new piece, the web and rail base remaining permanently in place. Stepped heads and those with a groove similar to the ones in use to-day were also tried.

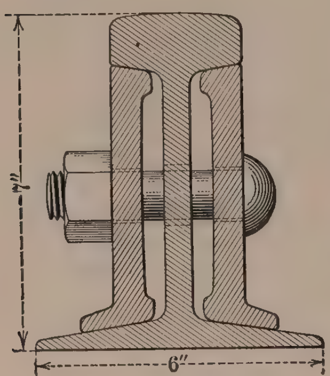


FIG. 213. T-Rail.

The types of rails encountered to-day are the grooved rail, the stepped rail, and the T-rail, as shown in Figs. 211, 212, and 213, respectively. When the car track occupies a space inaccessible to other traffic it is quite customary to use the T-rail. Although this form of rail is also adopted sometimes for track construction within the carriageway, special means are taken to form a groove so that the result, as far as the traffic is concerned, is practically the same as if a grooved rail had been used. A rail with a stepped head has been commonly used, but offers considerably more obstruction to traffic than a grooved rail. The smoothest track from the standpoint of other traffic crossing over it is without doubt constructed with grooved rails. This

type is now being largely employed both in this country and in Europe. There are several forms of grooved rails in use, the principal variation being in the position of the inside lip with reference to the tread and the shape of the groove. In some types this lip is short and the inside edge is below the plane of the head, while in others it is wide and ends in almost the same plane as the tread part of the rail. Rails are made of different depths, varying from about 4 to 9 inches. The 9-inch rails are generally designated as girder rails. A rail of this depth is required if any form of permanent pavement such as wood block, stone block, or sheet asphalt, etc., is to be built next to the track, in order to give sufficient room for a good thickness of concrete over the tie to support the pavement above.

Rail Joints. The weakest point in the rail is the rail joint. It is customary to form the joints with splice bars, similar to those used on steam railroad tracks. Rail welding, which not only makes a more permanent track, but also makes the rail a better conductor for the current, is gradually replacing this form of construction in the best practice. When the welded rails are imbedded in the surrounding pavement they need no provision for expansion and contraction, since changes in temperature simply develop some stress in the rails.

Foundation. The simplest form of track foundation is that of imbedding wooden ties in a bed of gravel or broken stone. This method is ordinarily used for tracks constructed on high ways outside of built-up districts, for tracks on streets that are not surfaced with a permanent pavement, and fort racks that are built on a right of way which is inaccessible to other traffic. When the tracks lie within the carriageway and are flush with the surrounding surface, this type of foundation may be used if the surfacing of the adjacent carriageway is of macadam. The maintenance expenses for the surfacing even in this case, however, will be greater due to the presence of the track.

It is absolutely essential in track construction which is flush with the roadway and adjacent to pavements of wood block, granite block, brick, or any form of bituminous pavement to

provide a foundation that will make the track as rigid as possible. The work should be done in such a manner as to reduce to a minimum the maintenance and renewal work incident to the track. To provide a permanent foundation, concrete is

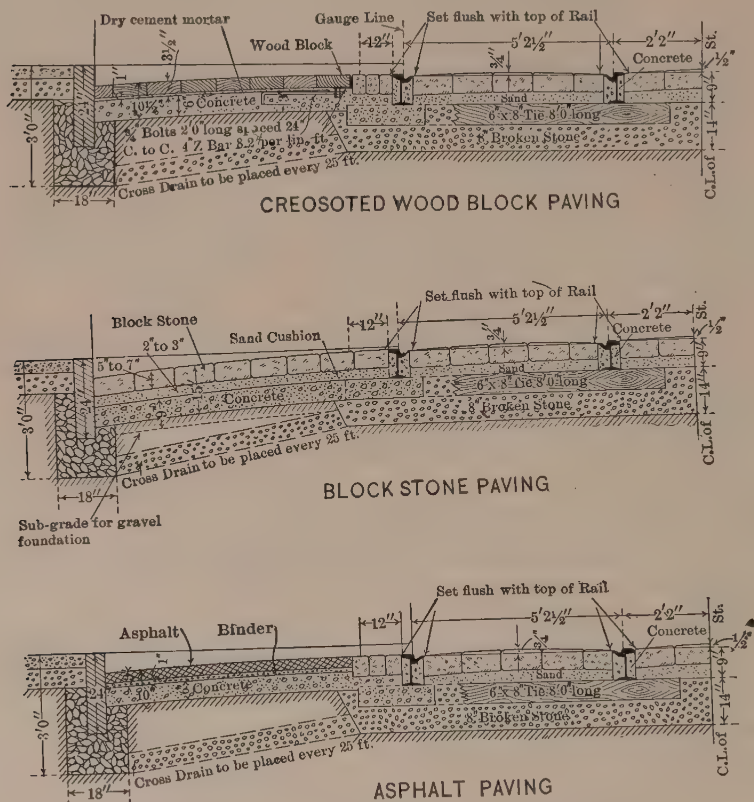


FIG. 214. Track Construction, City of Pittsburg.

used. The ties are laid on a bed of ballast or concrete which extends underneath the full width of track. Concrete is filled around and in some cases over the ties. Fig. 214 shows the foundation required for tracks laid adjacent to these types of pavements in the City of Pittsburg, Pa. Note that in this construction a stone drain leading from the foundation underneath the track to the gutter drain is required every 25 feet. It is

very important that the track should be thoroughly drained, as otherwise the water which is bound to seep through will soften

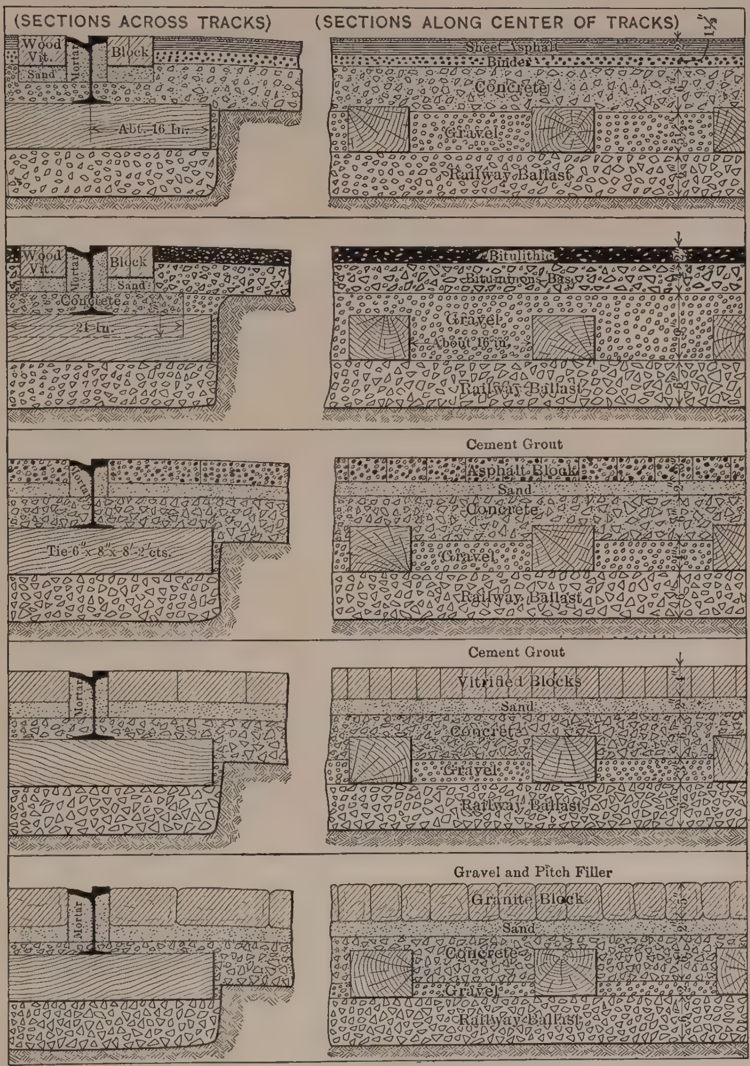
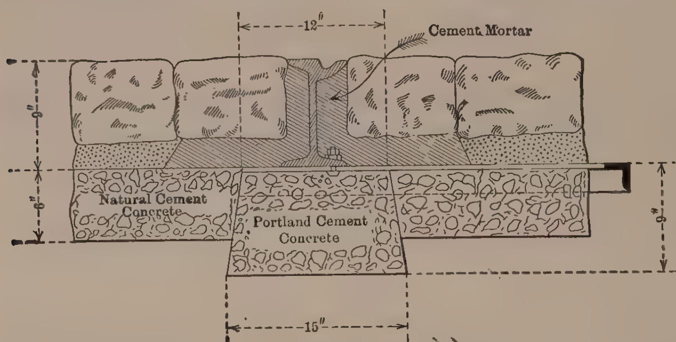


FIG. 215. Track Construction, City of Baltimore, 1911 Specifications.

the foundation and cause trouble. In Fig. 215 is shown the track construction as required by the 1911 specifications of the

City of Baltimore, Md. In some cases the wooden cross-ties are omitted and a longitudinal support of concrete is built under each rail. The rails are tied together at intervals with tie rods, which are imbedded in the concrete between the rails. A foundation of this type which is recommended for use by George W. Tillson, M. Am. Soc. C. E., is shown in Fig. 216. The tie bars are spaced 10 feet apart and are bolted to the bases of the



From Tillson's "Street Pavements and Paving Materials."

FIG. 216. Longitudinal Support for Rail.

rails as shown. Special forms of support for the rails have to be used in some cases where the third rail or other device for delivering the current is below the ground. A casting which is typical of those used in New York City in cases of this kind is shown in Fig. 217. They are spaced about 5 feet apart.

When concrete is used in the foundation as above described, it should be allowed to set up before cars are run on the track. Where a double track exists the cars can be shifted from one track to the other without any great inconvenience while the foundation is being constructed. Where it is a single track and the street is sufficiently wide a temporary turnout can be put in to take the cars. When cars have to be taken over the track during the construction some special means will have to be provided for supporting the track so that the concrete will be injured as little as possible.

In Germany reinforced concrete blocks previously moulded have been laid underneath the rails. As described by Fred-

derick Gerlach at the Second International Road Congress, "The blocks, which are 5 inches thick, 31 inches long, and 20 inches wide, are so moulded that in the top surface a trough is provided which is wide and deep enough so that when the rail is set in it the head of the rail will be flush with the surface of the block. Bolts are provided in each block so that rail fastenings may be put in and be attached to the rail base. The whole block is thoroughly reinforced and the reinforcing rods are allowed

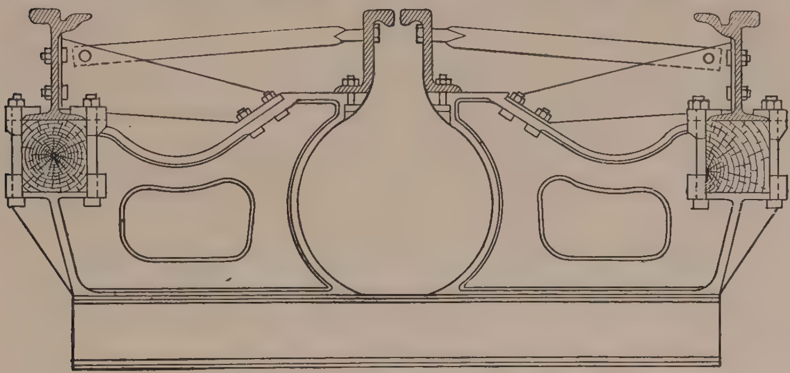


FIG. 217. Casting Support for Rails.

to project beyond the faces of the blocks, which are parallel to the rail so as to bond with the concrete that is later put in between the rails. The blocks are placed in the bottom of the trench in which the rails are to rest and are first covered with a viscous asphalt. They are then pushed under the rails, which have been jacked up to receive them, and the rails are then screwed down to the fastenings. The space between the bottom of the blocks and the earth roadbed is then carefully filled with a dry mixture of concrete, which is carefully tamped. After a fairly long section is completed in this manner, the bolt holes are run in with liquid cement and the space left between the rails and the side walls of the reinforced concrete troughs is filled with asphalt. The space then left between the faces of the blocks and between the rails is filled with well-rammed concrete. These reinforced concrete blocks are laid close enough together so that the joints between their ends are practically

closed up by pouring them with cement mortar. Cross-ties are done away with. In this construction the rails do not come in contact with the concrete at all, but, on the contrary, are separated from it by the lateral projections of the reinforced concrete blocks and from these again by asphalt. In cases of renewal the asphalt can be readily removed by means of heat, and after the nuts are unscrewed from the fastenings, the rails can be easily lifted out."

Surfacing Adjacent to Rails. The franchises of the street railway companies generally stipulate both in this country and in Europe that the company shall construct and maintain the pavement over the area covered by its tracks and for a distance from 18 inches to 2 feet outside of the rail adjacent to the carriageway. In Philadelphia a great deal more is required of the traction companies, as in 1892 it was agreed between these companies and the city that the companies should pave and maintain the streets in the city from curb to curb on which any of their tracks were placed. The franchises also usually require the traction companies, to maintain the pavement next to the rails in as good condition as the adjoining pavement, but the enforcement of these stipulations has been extremely difficult in certain localities. It has been found necessary to use special methods of construction along and between the rails in order to procure the best results.

If the rails are of sufficient depth to provide room for the block and a firm foundation over the ties, brick, wood and stone block pavements can be constructed up to and between the rails, as may be seen by examining Figs. 214 and 215. Special forms of brick blocks are used in some cases next to T-rails, which have one edge concaved. The concaved edge is placed next to the rail head and forms a groove. Where traffic is not too heavy this type of block has been satisfactory. Although bituminous pavements are constructed up to and between the rails, better results have been obtained when some form of blocks has been placed between the edge of the pavement and the rail, as shown in Figs. 214 and 215. There are instances where a track is paved with granite or brick blocks for the full width

between the rails and for 18 inches to 2 feet outside regardless of the type of surfacing in the remainder of the pavement, as shown in Fig. 214. The space on either side of the rail web underneath the rail head is generally filled with cement mortar, as is shown in Figs. 214 and 215. Some engineers believe, however, that much better results are obtained by using a stiff bituminous material.

On highways without built-up districts tracks constructed with shallow rails resting on ties imbedded in gravel will frequently be encountered. If the adjacent roadway is to be constructed of bituminous concrete, or bituminous macadam, the pavement cannot be constructed up to the rail with the expectation of its lasting very long. If the rails are so shallow that blocks cannot be laid on edge between them and the pavement as previously described, some other method has to be used. An 18-inch strip of waterbound macadam has been found to work satisfactorily in such cases where the tracks are at the sides of the road. Paving blocks laid flat and cobblestones have also been used with good results to pave the 18-inch width.

Care should be taken in track construction not to construct the pavement between the rails or between the tracks with a crown that will be out of proportion to that used in the remainder of the pavement. Thorough surface and subdrainage of the tracks should also be provided.

CHAPTER XXIII

PIPE SYSTEMS

Kinds of Systems. Pipe systems are to be found beneath streets in all cities. The business of some corporations controlling subsurface systems is so far-reaching in extent that their service pipes extend into the outlying districts beyond the city proper. As a general rule water supply pipes and pipes for the conveyance of sewage are the first systems installed in the development of a city. The universal use of gas as a means of light adds one more pipe service which must be so placed as to be available to the abutting property. Telegraph, telephone, and electric light wires, when these systems were first used, were carried above the ground. Although this practice is still common, in the business districts of many large cities the wires are now being laid in conduits below the ground. In fact, the time will come when most of the overhead wiring in the cities will be eliminated since the low maintenance cost of the underground construction makes it an economical proposition. Vaults underneath the sidewalks, subways underneath the streets, car tracks on the surface with their special construction sometimes for carrying current beneath the surface, pipes for carrying heat or refrigerating fluids from a central plant, pneumatic tubes, pipes for house connections, are all present in many cases to further complicate the problem. An engineer must assume, then, that pipes for sewage, water, and gas are an essential part of the development of any built-up district, and in designing the streets due allowance must be made for the accommodation of such systems. No one can forecast the future development and growth of places that now are seemingly unimportant, for it is often the case that such places grow rapidly, and, as a necessary part of their development, the conveniences afforded in a city are demanded. It is advisable, therefore, to study conditions in a community very carefully.

As may be inferred, these systems are not all built at the same time. The water supply and sewage systems are generally installed by the municipality, the custom being to build and extend these systems as the growth of the locality demands it. Frequently it is necessary to provide additional lines of pipe for both systems on streets in the older parts of the cities where the systems that were first laid have proved to be inadequate. The gas pipes, conduits for telephone, telegraph, or electric light wires may be laid by as many different corporations and at various times. In a great many of our cities extremely poor records showing the location of their services have been kept by these private corporations. With all of these various systems underneath the surface between the property lines and the consequent work of installation, repairs, connections, etc., it is not surprising that the streets are continually in a state of upheaval. This condition of affairs can only be alleviated by proper administrátion and legislation. This fact is true particularly of the municipalities of the United States.

Pipe Subways. The use of subways in which all pipe systems might be placed would do away with a great deal of the trouble of street disturbances which are now so prevalent in those places where pipe systems exist. The construction of subways for this purpose, however, is very costly and for this reason would be financially impracticable except in the very busiest and most important streets of large cities. Many European cities have pipe subways of varying lengths. In London there is a total of about seven miles. In Paris the sewers, which are of large dimension, are used for pipe subways. It is the belief of many engineers that the gas pipes should be excluded from subways in which electric cables are placed, because of the danger of explosion, which would occur with gas from a leaky main coming in contact with an electric spark. The experience of Paris has been that this danger is largely eliminated if the subway is well ventilated.

Location. Many of the services enumerated above have connections running to the houses which face on the street, and therefore they must be placed somewhere between the

property lines. This available space is generally divided into two sidewalks and one or more carriageways. In some cases a narrow parking space is left between the curb of the walk and the paved sidewalk, which plan, however, will generally only be found in the residential parts of a city. On wide boulevards liberal space is sometimes provided between the carriageways on each side. Unless the sidewalks or parking spaces are very wide it is absolutely necessary to locate some of the pipe systems in the carriageway. Where vaults, which extend to the surface, are constructed underneath the sidewalk, the use of the space underneath the sidewalk is no longer available for the services. As was mentioned in Chapter IV, ordinances in some cities now prevent the construction of such vaults within a distance nearer than four feet to the surface of the sidewalk, thus leaving this space for the location of subsurface pipes.

As far as the advantages to the street pavement are concerned, the fewer subsurface systems underneath it, the less the number of disturbances to which it will be subjected. Since it is rarely feasible to have a street without any pipe systems beneath it, the principle to be kept in mind is to place those systems beneath the carriageway which will be disturbed the least and locate them in such a manner that if repair work is necessary, it may be accomplished without disturbing the traffic to any great extent. If all of the different systems can be laid in a street before the carriageway is surfaced, and if the house connections can be extended to the property lines at the same time the installation of the different systems is made, such a procedure will prevent, to a large extent, disturbances to the carriageway at later periods. The width of the carriageways and sidewalks is so variable that each street might be said to be a special problem. From the practice as set forth in the remainder of the chapter, however, it will be noted that there are a few underlying important principles to be recognized.

Sewers. The sewer, when a single line, is usually located in the middle of the street, the manholes generally being built on the line of the sewer. In some cities of France, however, the manholes for a sewer are built in the sidewalk and connected

with the sewer by a branch wherever the sewers are large enough to be entered. Sewers are of such a construction that there is very little possibility of their being disturbed, if the house connections are carried out to the property lines at the time of the installation of the service. The use of two lines of pipe, one on each side of the street, is economical only when the expense of the second line and its connections is less than the cost of the connections from a single line placed in the center of the street. When constructed as a double line the sewer pipes are sometimes placed underneath the sidewalk instead of the carriageway. The depth at which a sewer is placed is, of course, very variable, since the sewer system must have a gradual fall to the point of outlet, and to obtain this fall will necessitate laying the pipes much deeper in some streets than in others, depending upon the topography of the surface.

Water Pipes. If a water pipe is laid beneath the carriageway, the surface of the carriageway is liable to be blown up in the event of a break in the pipe where the pressure is of any great amount. On the other hand, if the pipe is placed beneath the sidewalk, there is the danger of undermining the building foundations. The depth at which water pipes are laid beneath the surface is governed principally by the climate. There must be enough cover on top of the pipe to prevent the water from freezing. In a locality which has a climate similar to New York or Boston, a depth of about 4 feet is customarily provided.

Gas Pipes. As far as the gas main is concerned, one disadvantage of locating it in the carriageway when the latter is surfaced with sheet asphalt is the consequent destruction of the pavement if any large leaks occur. On the other hand, when placed in the sidewalk close to the building line, any leaks in the gas pipe may prove dangerous to the residents in the buildings.

Cable Conduits. The conduits for carrying the cable wires may well be placed underneath the sidewalk.

Typical Examples. Since the practice relative to the location of the different kinds of services is somewhat varied, it may perhaps best be shown by describing the practice in several places.

Antwerp. In one of the streets of Antwerp, Belgium, in which double lines of systems are used, with the exception of the sewer a line being placed on each side of the street, the arrangement of the pipe lines is as follows: the water main, gas main, and light cables are placed underneath the sidewalk and at a distance in from the curb of 1.6, 4, and 5.6 feet respectively. The depths at which the pipes are respectively laid are 3.3, 2.6, and 2 feet.

France. In France the wire conduits are usually placed underneath the sidewalks, and where there is one water main in each street, it is placed underneath the carriageway. Water pipes on each side of the street underneath the sidewalk are found only in some of the principal streets of the largest cities. Gas pipes are generally placed underneath the carriageway.

Berlin. In Berlin the arrangement of the mains as described in a report presented before the Second International Road Congress is as follows: "The pipe systems are placed in the footway only when the breadth of the latter exceeds 16.4 feet, otherwise in the carriageway. The gas mains ranging up to 15 inches in diameter are placed under the footway; when larger than this they are placed in the carriageway. Water mains up to 9 inches in diameter are laid in the footways, when these have a width of 8 feet or more; when of greater diameter than this, or when the footways are narrower, they are placed in the carriageway. The electric cables, with the distance telegraph and telephone cables, are placed close to the line of the buildings, a strip of about 3½ to 5 feet in width being reserved for them. The tramway cable is laid next to the curbstone, while an intermediate position between the gas and water mains or drainage pipes is allotted to the lighting cables. With this arrangement the footway ground is utilized to the utmost, so much so that, even with a width of footway of 16.4 feet, there is no room left for the planting of trees."

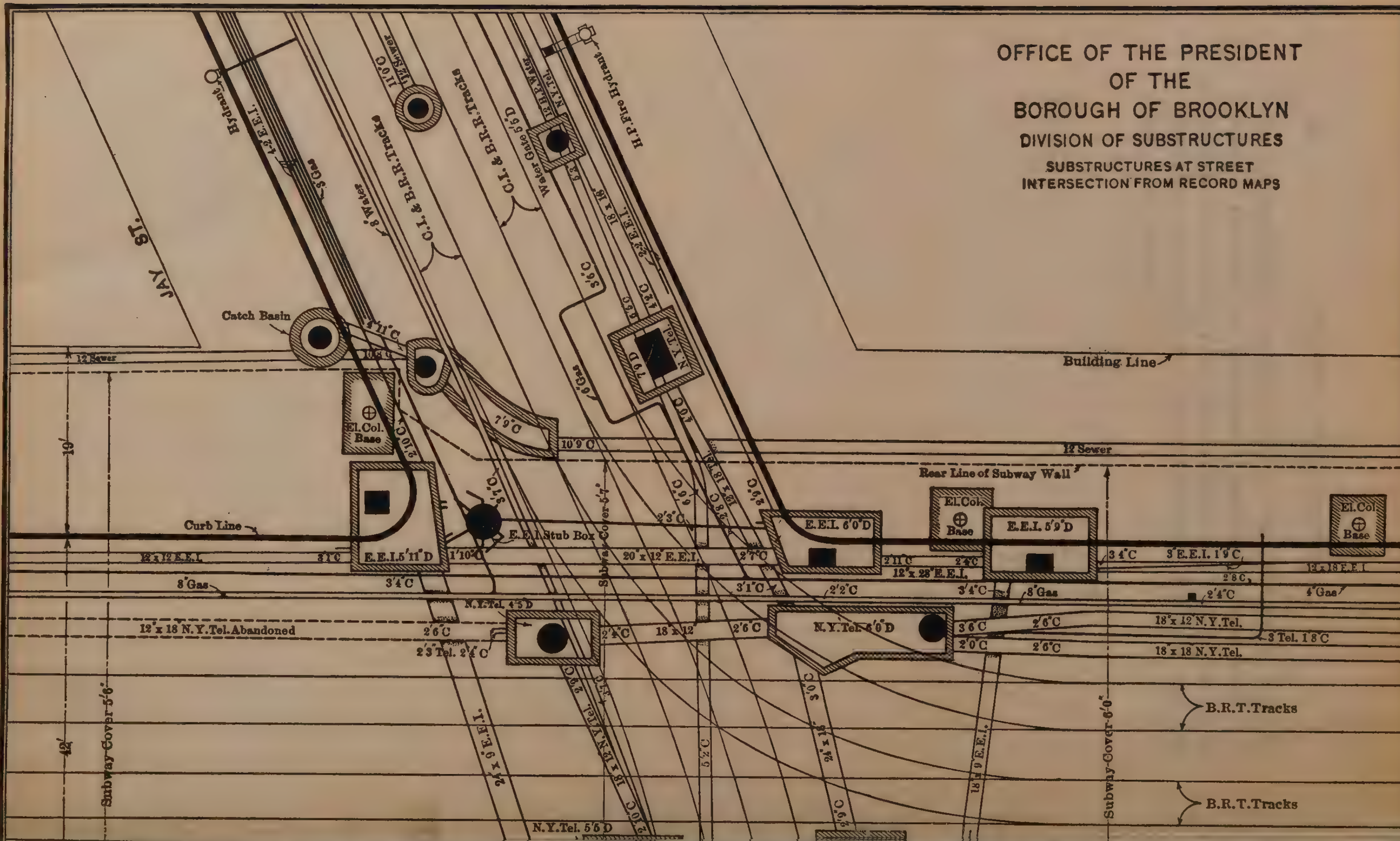
Budapest. A report presented before the same Congress relative to this question described the arrangement of pipe systems in Budapest, Hungary, as follows: "The sewer is generally placed in the middle of the street. On streets less than

49 feet in width the gas main is placed on one side of the street under the roadway, 3.3 feet away from the curb, and the water main occupies a similar position on the other side of the street. The electric light and telephone cables are laid under the sidewalks as near the houses as possible. The telephone cables are placed in concrete block conduits, which contain in some cases as many as forty-eight cables and are placed sufficiently deep so that the other services to the houses can pass over them. On streets of a greater width than 49 feet there are placed both a water main and a gas main on either side of the street, 3.3 feet and 6.6 feet away from the curb respectively. On streets of a still greater width, 82.0 feet and more, on each side of the street the pipes are placed as follows: a water main at the curb, then the secondary street sewers, and, at a distance of about 10 feet from the curb, the gas main. Gas mains are placed under the surface at a depth of from 3½ to 5 feet. Water pipes are generally laid from 4½ to 5 feet below the surface of the pavements."

Brooklyn. Plate 3 shows part of a record map, representing the substructures at a street intersection in Brooklyn, New York, which gives a very good idea of the complex arrangement that may be found beneath the streets in the business district of large cities.

Repaving Trenches. It is very difficult to repave a surface over a trench which has been made for the purpose of installation or repairing any pipe systems, so that it will be in as good condition as the original pavement. There is more or less settlement of the earth in the trench, which will cause a similar depression in the surface. The fact that the pavement replacements are not properly supervised and that frequently the work is done by people not familiar with the details of construction, gives results which are particularly disastrous. One of the prime requisites is that the earth in being filled back in the trench should be thoroughly compacted. This can be accomplished by hand tampers tamping the earth in very thin layers, or puddling the earth with water will also tend to compact the same. When the pavement in which the trench has been cut

is supported upon cement concrete, the foundation may be replaced by either of the following methods in order to give it additional strength: first, the depth of the concrete may be increased, or, second, it may be reinforced and tied into the adjoining concrete.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JAY ST.
Hydrant
4-2 E.E.I.
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C.I. & B.R.R. Tracks
Catch Basin
Water Gate 5'6"D
H.P. Fire Hydrant
N.Y. Tel.
Building Line
12 Sewer
Rear Line of Subway Wall
El. Col. Base
Curb Line
E.E.I. Stub Box
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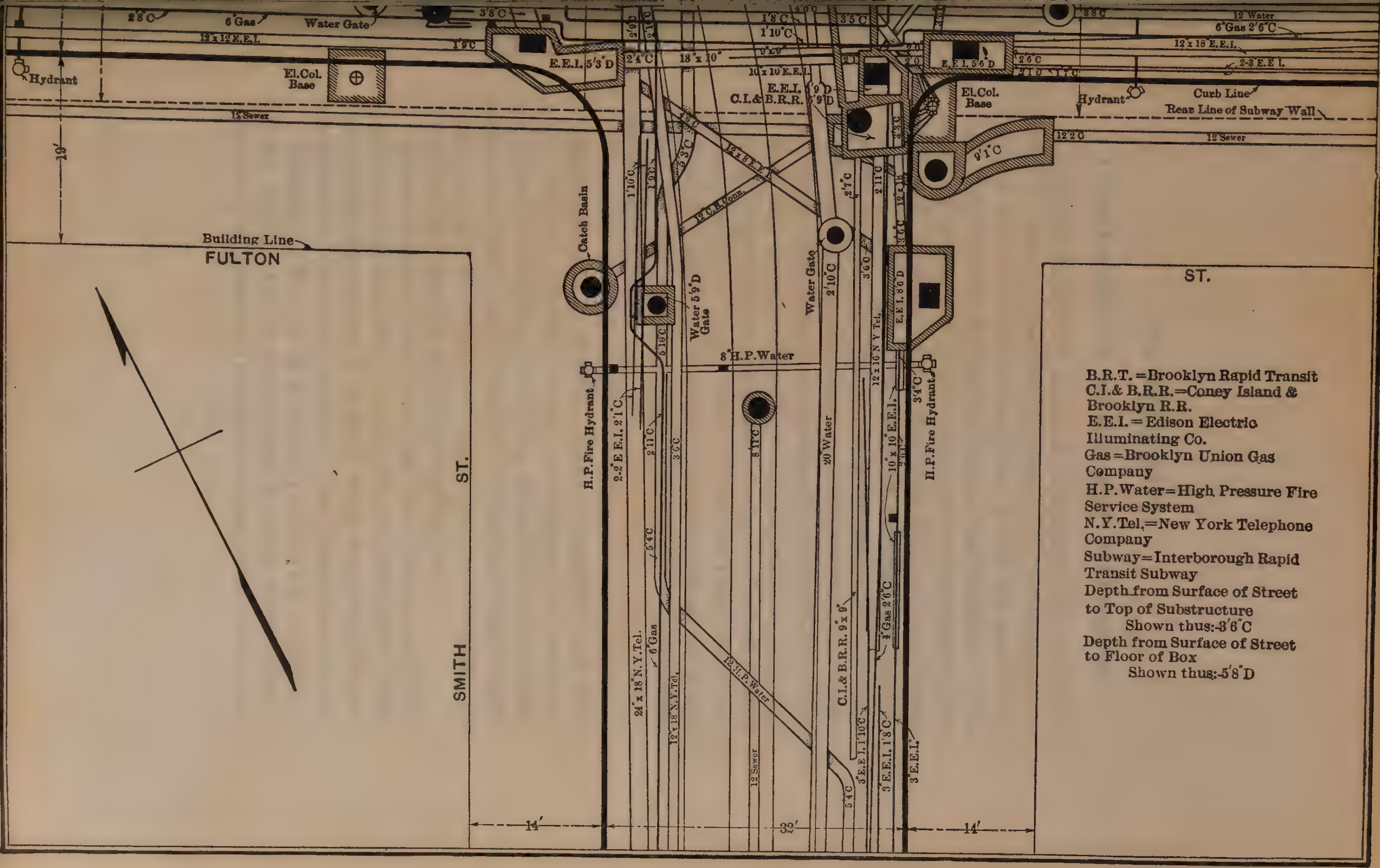
E.E.I. 6'0"D
E.E.I. 5'9"D
N.Y. Tel. 6'9"D
N.Y. Tel. 4'5"D
N.Y. Tel. 5'5"D
12 x 12 E.E.I.
20 x 12 E.E.I.
12 x 28 E.E.I.
3 E.E.I. 1'9"C
8 Gas
4 Gas
12 x 18 N.Y. Tel. Abandoned
18 x 12 N.Y. Tel.
18 x 18 N.Y. Tel.
3 Tel. 1'8"C
2'3" Tel. 2'4"C
24 x 9 E.E.I.
18 x 9 E.E.I.
24 x 18
B.R.T. Tracks
Subway Cover 5'6"
Subway Cover 5'7"
Subway Cover 6'0"
19'
42'



From "Municipal Journal and Engineer."

PLATE 3. Map Showing Location of Substructures.

CHAPTER XXIV

COMPARISON OF ROADS AND PAVEMENTS

The determination of the most economical and efficacious method of construction and maintenance to be employed on highways of various classes constitutes one of the most interesting subjects which the highway engineer has to consider. The solution of the problem depends upon many variable factors, all of which must be given due consideration and the proper value attached to each. The great variety of materials and methods of construction and maintenance used, together with the absence of such essential information as traffic censi, cost data, etc., makes it a difficult matter sometimes to reduce all of the different types of roads to a comparable basis for a given location. In many localities where engineers have adopted some one general method for construction or maintenance it may be found that such methods, although they may be successful as far as use is concerned, are not the most economical types which would be equally efficacious.

Essentials of an Ideal Road or Pavement. An ideal road or pavement should be durable, noiseless, suitable for road users, easily cleaned and made dustless, non-slippery for horses and all classes of vehicles under varying climatic conditions, easily maintained, should yield neither dust nor mud, have a low tractive resistance, low first cost, low annual cost, low maintenance charge, and an aesthetic and impervious surface.

A consideration of these important characteristics reveals the lack of accurate data which are available relative to each. However, certain information is at hand which materially aids in a comparison of roads and pavements from different standpoints.

Durability. The life of a road or pavement is expressed in (a) the number of years during which it can be maintained in a satisfactory condition at a cost which has not reached an amount

so that reconstruction is economical, and (b) the total number of tons per yard or foot of width that the road or pavement is subjected to during its life. As durability is a function of a number of variables among which the amount of traffic is of primary importance, method (b) conveys more information in many cases than the first method.

In 1911 George W. Tillson, M. Am. Soc. C. E., assigned eighteen years as the average life for sheet asphalt pavements, twenty-five years for granite block pavements, "assuming that only the heavy traffic or streets with steep grades are paved with granite," and twenty to twenty-five years for brick pavements. Rather than give a definite estimate he states that "creosoted blocks have not been in use long enough to enable one to determine from experience how long they will last or what will be the cost of repairs. The first pavement of this character laid in the East was on Tremont Street, Boston, and has been there since 1900. It is now in good condition and has had very little repair done upon it."

The other method is employed by John A. Brodie, M. Inst. C. E., in a comparison of the tonnage life of different kinds of stone block and ordinary macadam.

"Taking heavy-traffic streets first, experience shows that accurately dressed setts—6 inches deep by 6 inches to 8 inches long by 4 inches wide, laid on a sound concrete foundation at least 8 inches deep, with a small sand bed between the underside of the sett and the concrete, the joints being thoroughly racked with hard shingle and afterwards grouted with a permanent pitch mixture, which prevents any movement in the stones, and renders the whole surface perfectly impervious to weather—give a life equal to at least 7½ million tons per yard width, and under these conditions this life has often been exceeded.

"It is at present impossible to say whether an equal tonnage-life can be obtained from the similar shallower 4-inch class of construction in streets taking, say, 60,000 tons per yard of width, as this would mean a life exceeding 100 years; but experience shows that the total average wear of the setts has been exceedingly small, and it is a fact that many such streets exist in

Liverpool today, having a life of from twenty-five to thirty years without requiring any important repairs during that time due to wear of the material.

"When the same quality of stone is used in ordinary macadam laid 6 inches to 7 inches deep on a sound, hand-packed foundation, experience shows that the tonnage-life of the surface before requiring to be recoated is enormously decreased, and instead of 7½ millions, a figure about 100,000 tons only, or about 75 times less than the result for setts previously given, has been obtained on a street of moderate traffic—a somewhat startling difference."

Sanitary Qualities. The sanitariness of a road or pavement is based on its imperviousness, smoothness, and freedom from dust and mud. From the standpoint of the public health noiselessness might properly be considered under this head, as it affects the health of nervous people. L. Mazerolle, Engineer of Bridges and Roads of France, compares certain pavements from this standpoint in the following words:

"From the point of view of hygiene the best road surfacing material is the one which, having no joints whatever, does not absorb the liquids falling on the roadway. Compressed asphalt is theoretically the best road surfacing from this standpoint. Stone block pavements seem subject to criticism because of the apparent infiltration of water through the sand joints. This infiltration is frequently found very slight where old pavements are removed. Wood pavements are often accused of absorbing filthy liquids, but experiments carried out at Paris refute this theory. Altogether it appears that public health is less affected by the nature of the material constituting the road surface than by the quantity of dust produced and by the extent to which cleaning operations are carried out."

Noiselessness. George W. Tillson*, M. Am. Soc. C. E., has presented the following admirable discussion on this property of roads and pavements.

"A quiet pavement has become particularly important at this time. With the strenuous life of the modern cities the nerves of

* See *Engineering and Contracting*, October 18, 1911.

the workers must be protected, and it is the testimony of all brain workers that noise is a great disturber. Constant complaints are coming to city departments not only of the great disturbance to the nerves of the workers but actual loss of time in schools, offices and court rooms, and interruptions in churches on account of the noise over rough pavements. Hospitals all complain of the noise on account of the damage done to patients.

"Of the different kinds of pavements herein stated, one of wood blocks is least noisy, followed by asphalt, asphalt block, bitulithic, brick, and granite as the most noisy. It often happens, however, that on account of grades or extremely heavy traffic it is necessary to lay granite even where a quiet pavement is desired. In this case special care must be used to reduce the amount of noise to a minimum."

Slipperiness. The comparison of pavements from the standpoint of slipperiness has naturally been confined by early investigators to the effect on horses. It is evident that future investigations along this line should include consideration of slipperiness for all classes of vehicles under varying climatic conditions. From the former viewpoint, that is, with reference to horses, stone block with joints filled with a bituminous filler ranks first as a non-slippery pavement. Hillside vitrified brick or ordinary vitrified block constructed with a bituminous filler is adaptable for steep grades. The other pavements and roads rank in the following order as non-slippery: gravel; macadam; bituminous concrete; stone block and brick with cement grouted joints; bituminous macadam; bituminous surfaces; sheet asphalt and wood block. The table gives a general idea relative to the maximum grades on which it is permissible to use different types of roads and pavements.

Granite with bituminous filled joints	15 to 20%
Brick with bituminous filled joints	10 to 15%
Earth Road	10%
Gravel Road	7 to 10%
Macadam Road	7 to 10%
Bituminous Concrete	5 to 8%
Stone Block and Brick with cement grouted joints	5%
Bituminous Macadam	3 to 5%

Macadam with bituminous surface.............	3 to 5%
Sheet Asphalt................................	3 to 4%
Wood Block...................................	2 to 3%

Haywood Report. In 1873 William Haywood submitted a report to the Sewer Commissioners of London which included a comprehensive comparison of rock asphalt, granite block and wood block pavements from the standpoint of relative slipperiness. As a description of methods of investigating slipperiness the report is of interest to American engineers, but the conclusions stated cannot be used to advantage, as the types of construction described are not in common use in America. Mr. Haywood's reports are included in the United States Special Consular Reports entitled "Streets and Highways in Foreign Countries."

Resistance to Traffic. The tractive force required to draw vehicles over a given type of road or pavement is of primary importance as a factor in the selection of the wearing surface. Naturally the weight to be attached to this factor will depend to a certain extent upon the character of the traffic which will use the highway. Investigations have been conducted upon which have been based certain conclusions which may serve as general guides.

In discussing the effect of grade and the character of the surface on tractive force, Professor E. B. McCormick of the Kansas State Agricultural College stated certain general premises, described various experiments conducted with a horse-drawn dynamometer wagon, and drew certain conclusions as contained in the following abstracts:*

"There are so many variables that enter in to affect the draft of any vehicle, that it is difficult, in a test made under actual working conditions, to separate the effect of any one of the many, for the same reason it is not safe to put too much confidence in the results obtained from a limited number of tests, or to compare the results made by different persons under unlike conditions and at widely varying times. Some of the

* See *Southern Good Roads,* January, 1913.

variables that are sure to enter in are: 1, the team; 2, the driver; 3, nature of surface; 4, conditions of the surface; 5, grade; 6, width of tire; 7, diameter of wheel; 8, design and condition of vehicle; 9, magnitude of load; 10, curves; 11, slopes.

"The tests conducted under the supervision of the writer, since 1908, have been run with a traction dynamometer wagon. The dynamometer proper is suspended from the bed of a Studebaker truck about midway between the front and rear axles. The pull is transmitted by the tongue directly to the dynamometer, which pulls on the rear axle. The draft is measured by the compression of two carefully calibrated coil springs, and is transmitted through gears to a brass point which marks the record on sensitized paper operated by friction rolls but over a flat platen.

"*Grades.* Increasing the grade decreases the load that can be hauled, in each of three ways:

1. The required pull per ton is increased.

2. The possible pull of the horse is decreased by the effort required for the horse to raise his own weight through the grade.

3. The effective pull of the horse is diminished by a change in the angle of the application of the pull.

"There are no ways of overcoming the first two losses; the third, however, can be nearly if not entirely eliminated by a change in the methods of hitching. A comparison of the figures in the following table will show very clearly the decrease of effective work with the increase of grades. The first column shows the actual pounds of pull required to draw a gross load of 5,270 pounds over a dry hard earth road, solid and well compacted, no dust, and using 1½-inch tires. These figures are from a test made at the Kansas State Agricultural College on August 12, 1912. The third column gives pounds pull required per ton as figured from values in the second column. The fourth column gives draft in pounds per ton as taken from results of tests on macadam roads. The fifth column shows the possible pull of a 2,800 pound team on the different grades. These figures assume that a team can exert a pull equal to one-third of its weight for a short time, on the level, and that on

grades the tractive effort of the team decreases an amount equal to the grade resistance due to its weight, as calculated by the formula:

$$X = \frac{W}{3} - \frac{W}{100} G$$

Where W = Weight of Team
X = Tractive Effort of Team
G = Percent of Grade.

Percent Grade	5270 Pounds	Dirt Road Per Ton	Macadam Per Ton	Possible Pull of 2800 lb. Team for a Short Period of Time
0	263.0	100	38	933
1	315.7	120	58	905
2	368.4	140	78	877
3	421.1	160	...	849
4	473.9	180	118	821
5	526.5	200	138	793
6	579.2	220	...	765
7	631.9	240	...	737
8	684.6	260	...	709
9	737.3	280	...	681
10	790.0	300	...	653

"A comparison of these figures will show that the necessary pull on a 10 percent grade, over that on a level, is 200 percent for a dirt road, while the decrease in effective pull for any given team is nearly 30 percent, and that for a dirt road any given team can pull on a 10 percent grade only two-ninths of the load that it can draw on the level.

"It must be remembered that while a team may exert an effort equal to one-third (or even one-half) its weight for a short length of time, it cannot do so for an extended period. The value in such case, as given by different authors, varies one-tenth to one-fifth the weight of the team.

"It is customary to state the probable pull of a horse or team in terms of its weight. This of course is not accurate, as a well-trained team of 2,000 pounds will oftentimes outpull a poorly trained team of 2,600 pounds or 2,700 pounds."

Materials. Based upon the results obtained by various investigators Professor McCormick has compiled a table to

show the relationship existing between different wearing surfaces and the tractive force in pounds per ton. Only a part of the table is given here.

Surface	Tractive Force per Ton
Earth packed and dry	100
Earth—muddy	190
Sand—loose	320
Gravel—good	51
Gravel—loose	147
Macadam—average	46
Sheet asphalt	38
Asphaltic concrete	40
Vitrified brick—new	56
Wood block—good	33

Annual Cost. The relative economy of different types of roads and pavements can only be ascertained by comparing the annual costs. The annual cost is a combination of the following variables: interest on the initial cost of the road, the annual maintenance charge and an annuity which will in N years, the so-called life of the road, provide a fund equal to the cost of reconstruction. If we let C = annual cost, A = first cost, r = rate of interest, I = annual maintenance charge, and x = annuity, the annual cost may be expressed by the formula

$$C = A\,r + I + x.$$

In the case of types of roads permitting partial reconstruction every M years, a second annuity y should be included in the above formula to take care of this periodical reconstruction through N years or the total life of the road. In order to make a fair comparison of the different methods, the same standard of maintenance in each case should be insisted upon.

Although theoretically the pavement giving the lowest annual cost would be the most economical one to build, there are other financial considerations which sometimes make it necessary to select some other type of pavement. For instance, the amount of money at hand for the improvement may not be sufficient to pay for the first cost of construction of a pavement which would give a low annual cost. In large cities the cost of cleaning

pavements is an item that should be taken into account, since the saving in this respect might be more than offset by the difference in annual costs between two pavements. Again, a road or pavement that might be the most economical would require such frequent repairs as to interfere with the traffic and business conducted on it.

From the foregoing discussion it is evident that the annual maintenance charge (I) and the annuity (x) are the variable factors to which it is difficult to assign definite values in many cases. First cost, although varying to a marked degree for different classes of pavements in various localities, may be assigned definite values. The initial costs of various roads and pavements have been considered in detail in the preceding chapters, and hence will not be repeated here.

Maintenance. Unfortunately the standards of maintenance vary widely throughout this country. Hence reports relative to the cost of this item as a factor of annual cost are of little value except in those cases where it is known what the highway officials mean by the statement, "the road is well maintained." The ideal maintenance, which should be striven for in every case, is a method by which the surface of the highway is kept in as good condition as when accepted on the completion of construction. It is self-evident that it is only possible to conform to this ideal by the adoption of the principle of continuous maintenance. It is certainly deplorable that in the case of some of our public work the idea of maintenance possessed by certain lay boards will permit the surface of a macadam road to remain covered with loose broken stone caused by disintegration due to motor car traffic for a period of over two months. Obviously it is absurd to designate such a practice as maintenance. Rather it should be characterized as criminal negligence.

Annuity. The factor, annuity, is a function of the variable, the life of the road or pavement. George W. Tillson, M. Am. Soc. C. E., states that, from data collected in American and foreign cities, the estimated life in years of certain pavements may be taken as follows:

Granite block on 6-inch concrete, tar and gravel joints..........	25
Granite block on sand base, sand joints......................	20
Sheet asphalt on 6-inch concrete, 2-inch wearing surface, 1-inch binder..	18
Wood..	10 to 15
Vitrified brick on 6-inch concrete, pitch or Portland cement joints..	15

Examples. As illustrative of the method of analysis which should be employed in consideration of annual cost, a few examples will be cited.

In a given case it was decided to first construct a water-bound macadam and afterwards provide a bituminous surface by superficial treatment. The annual cost of a bituminous concrete pavement, finished with a flush coat which, under the traffic to which this road was subjected, would last five years, will be investigated for comparison. Granted that it will be necessary to reconstruct both roads by replacing the wearing surface of 2 inches every twenty years, the annual cost may be compared as follows. For the annual superficially treated road, the first cost was 67 cents, the interest charge at 4 percent, 2.7 cents, the maintenance charge 7 cents, composed of a 5-cent charge for annual bituminous treatment and 2 cents for repairs, the annuity 0.9 cent, based upon the cost of reconstruction. Hence the annual cost will be 10.6 cents. In the case of the bituminous pavement the first cost would, under the existing local conditions, be 90 cents, the interest charge 3.6 cents, the maintenance 2.5 cents, made up of a repair charge of 0.5 cent and the cost of the flush coat, having a life of 5 years distributed throughout this period, of 2 cents, and an annuity of 1.7 cents, thus making the annual cost, 7.8 cents, as compared with the annual cost of the superficial treatment of 10.6 cents per square yard.

As a further illustration of the application of the formula the annual cost of a granite block pavement laid on a 6-inch concrete base will be computed. It will be assumed that the first cost is $3.50 per square yard; interest at 4 percent; annual maintenance cost is 2.4 cents; that life is twenty-five years; that at the end of this time new blocks are laid on the old concrete foundation at a cost of $2.50 per square yard, and that in this

manner the life of the pavement is renewed for another twenty-five years. The annual cost then for fifty years, considering the whole pavement to be renewed at the end of that time, will be found as follows: $C = \$3.50 \times 0.04 + 0.024 + 0.023 + 0.060 = \$0.247$ for the first 25 years, $C = \$0.187$ for the second 25 years, and the mean of these gives $C = \$0.217$ average for 50 years.

Methods of Comparison. The primary object of a detailed comparison of the relative merits of various roads and pavements is to enable the engineer to determine within certain limits the method of construction and in some cases the method of maintenance which are adaptable to local conditions from the standpoints of economy and efficiency.

As an aid in comparison it is advisable to have at hand a table covering numerical values of certain factors which are susceptible to such form of comparison. The following table, which illustrates the treatment of the problem along these lines of investigation, gives assigned values for some of these characteristics of the different types of roads and pavements on the basis of ten for the value of the characteristic in an ideal pavement.

	Ideal Pavement	Sheet Asphalt	Brick on Concrete	Stone Block on Concrete	Wood Block on Concrete	Concrete	Bituminous Concrete	Bituminous Macadam	Bituminous Surface on Macadam	Macadam with Dust Palliative	Macadam	Gravel	Earth
First cost	10	3	5	1	1	6	7	7	8	9	9	9	10
Ease of traction	10	10	8	3	9	9	9	8	8	6	6	5	2
Non-slipperiness	10	4	8	7	4	6	7	7	7	8	10	10	10
Ease of cleaning	10	10	9	7	9	8	9	9	9	3	3	1	1
Noiselessness	10	7	6	3	9	6	9	9	9	10	10	10	10
Non-productive of dust	10	10	9	8	7	7	9	8	8	6	4	3	1

It must be borne in mind that it is absolutely necessary for each engineer to modify tabular information of this character in order that the values shall be based upon local conditions. For instance, it is obvious that the numerical values assigned to "First Cost" will vary materially in different sections. It is likewise apparent that it is impracticable to add up numerical

values blindly with the expectation that the type having the highest value is the pavement to be employed. In the great majority of cases one or more factors will also have a greater weight than certain other properties. Of course it is possible to weight the values of a table and then obtain totals for comparison. The totals obtained by the summation of numerical values of properties referred to in the above table must, however, be supplemented by values attributed to factors which are not covered in the table due to their complex and variable character. As examples of such factors may be cited cost of maintenance, durability, etc., which properties are intimately related to local conditions pertaining to a given highway.

In the table* on page 655 are given the factors for consideration recommended by Major W. W. Crosby, M. Am. Soc. C. E., in cases where the selection is confined to the following methods, use of palliatives, the surface treatment of macadam and gravel roads, the construction of bituminous pavements by penetration methods and by mixing methods.

Some engineers develop a classification based on the foregoing principles and as each individual problem arises assign the highway in question to a given class.

John A. Brodie, M. Inst. C. E., while Borough Engineer and Surveyor of Blackpool, England, divided the streets within his district into five classes, and determined the amount of traffic for which each class was suitable. His conclusions were as follows:

"Class No. 1. Foundation of Portland cement concrete 7 inches thick, covered with granite setts 5 inches to 6 inches in length, 3 inches in width, and 6 inches in depth; jointed with fine, dry gravel and boiling pitch and creosote oil.

"This class is suitable for main suburban roads with traffic up to 200,000 tons per yard width of carriageway per annum; impervious to moisture; noisy, but clean; gradients up to 1 in 40.

"Class No. 2. Foundations of Portland cement concrete 6 inches in depth, covered by specially selected Karri or Jarrah

* See Trans. Am. Soc. C. E., Vol. LXXIII, p. 6.

"DIAGRAMMATIC ARRANGEMENT OF CONTROLLING FACTORS INFLUENCING THE SELECTION OF THE METHOD TO BE ADOPTED"

Method to be used:	Physical Suitability of Results:	Esthetics; Traffic; Smoothness, or Firmness; Dustiness, or Cleanliness; etc.
	First Cost:	Equipment; Cost of materials; Cost of skilled labor; Cost of ordinary labor; Workable season; etc.
	Cost of Maintenance:	Repair equipment; Cost of materials; Cost of using materials; Workable season, and inter ference with repairs; Frequency of repairing; etc.
	Human, or Personal Elements:	Control by laymen, or by engineers; Local or personal prejudices or desires; Knowledge of facts by controlling authority; Tendency of controlling authority to accept other facts or theories; etc.

blocks 6 inches to 8 inches in length, 3 inches in width, 4½ inches in depth, laid close, direct on concrete, and grouted with boiling pitch and creosote oil.

"Suitable for first-class shop streets, with traffic of about 100,000 tons per yard width per annum; practically impervious, noiseless, clean, and dustless; gradients up to 1 in 40.

"Class No. 3. Foundations of hand-packed rubble 8 inches in depth, covered with 5 inches of tar-macadam.

"Suitable for residential streets having a light traffic of

20,000 tons per yard width per annum; impervious, noiseless, clean and dustless; gradients up to 1 in 24.

"Class No. 4. Foundations similar to No. 3, but 7 inches deep, with 2½-inch gauge water-bound granite, to a finished depth of 5 inches, blinded with fine granite chippings.

"Suitable for ordinary residential front streets with a light traffic of about 5,000 tons per yard width per annum; pervious, comparatively noiseless, dusty and sloppy; gradients up to 1 in 12.

"Class No. 5. Foundations similar to Nos. 3 and 4, 7 inches in depth, covered with Haslingden setts 6 inches to 8 inches in length, 4 inches to 6 inches in width, and 6 inches in depth; jointed with dry gravel and boiling pitch and creosote oil; laid with a concave cross-section and channel in center.

"Suitable for back (or secondary access) streets 9 feet to 18 feet in width, with a traffic of 60,000 tons per yard width per annum; impervious, clean, and dustless; very noisy; gradients up to 1 in 12.

"It is not claimed that the above-classified carriageway specifications are the best under all circumstances, but only that they are probably the most suitable for the author's district, or for use under similar conditions."

In connection with the general comparison the following conclusions* adopted at the Second International Road Congress which was held at Brussels in 1910 are worthy of careful consideration.

"1. Macadam, constructed according to the methods of Tresaguet and McAdam, causes dust and mud, is expensive to maintain, and is only suitable in large cities for streets where the traffic is not very great or heavy.

"2. The experimental work carried out in recent years with macadam improved by using a bituminous binder should be continued in order to determine the best methods of utilizing this kind of construction under varying conditions, so that this question may be submitted again at the next Congress.

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* See "Highway Engineering as Presented at the Second International Road Congress, Brussels, 1910," by Blanchard and Drowne, pp. 237–239.

"3. Stone pavement has great qualities of resistance and durability. Its maintenance is easy and economical, it produces practically no dust, and is suitable where there are tramway tracks.

"4. Stone pavement should be adopted in thoroughfares wherever noise is of little consequence, or when wood or asphalt surfaces are not suitable. It should consist of blocks which are regular in shape, durable but not slippery, and will wear evenly. The blocks should be laid with close joints upon a foundation.

"5. The Congress expresses the wish to see the trials of small block pavements continued wherever local circumstances and traffic conditions permit.

"6. Wood paving is noiseless, is not slippery if kept clean, and stands very heavy traffic. The use of it should be extended even to thoroughfares through which tramway lines run.

"7. The respective advantages of soft and hard wood blocks must be a subject of discussion at a forthcoming Congress.

"8. Asphalt pavements should be recommended, owing to their good qualities from the hygienic point of view, their ease of cleansing and of repair, and the small tractive effort required on them. This surfacing is almost noiseless and produces but little dust, but it is unsatisfactory adjacent to tramway rails.

"9. There is opportunity for its use in fashionable thoroughfares where the traffic is not severe, where there are no tramways, and where the gradients are very moderate.

"10. Finally, the trials of asphalt flag and block pavements should be continued with regard to those qualities not yet determined."

Factors Influencing Scientific Comparison. The small amount of scientific comparison of roads and pavements which has been undertaken in the United States is attributable to many causes among which may be noted the following:

First. Political interference in the selection of the men placed in control of highway work, and with the work of design, construction, and maintenance of roads and streets, and the interference by controlling bodies of laymen in the legitimate work of the highway engineer.

Second. The continual change in the personnel of the engineering staff in control of highway work.

Third. Division of responsibility in the supervision of highway work, particularly in municipalities, but also applicable in some states, as, for instance, those in which the state department supervises the design and construction, while the responsibility for maintenance is placed upon the county or town.

Fourth. The search by many officials for a panacea for the treatment of all classes of roads and streets.

Fifth. The comparatively small number of well-trained highway engineers who have devoted the requisite time and energy to the new problems which have arisen during the last decade.

Sixth. The non-application of the principles of scientific management to the varied problems confronting highway engineers.

Seventh. The comparatively infinitesimal amount of investigation which has been considered necessary as preliminary to the design of a road or street or a system of highways.

Eighth. The general meagerness of detail knowledge of the many different materials on the market and the varied methods in connection with which they may be used.

Ninth. A confusion of ideas on the part of many as to the reasons for the success or failure of a given road or pavement.

Tenth. Non-observance of the relationship between the adaptability of various methods and materials, the variability in the cost of labor and materials, and the accessibility of new materials and machines.

Records and Cost Data. It is apparent that records and cost data are essential if an intelligent comparison is to be made of the relative value of different types of roads and pavements. Unfortunately, particularly in the United States, the accumulation of data is rendered impracticable in many instances due to the frequent changes of administration of highway departments. Scientific investigations are thus terminated before sufficient length of time has elapsed to enable definite conclusions to be formulated.

Nelson P. Lewis, M. Am. Soc. C. E., considers that

"Cost records of highway work should indicate as clearly as possible the proportion of the expense chargeable to:

1. Permanent betterments, such as land purchases, grading, the improvement of lines and grades, masonry and steel bridges and culverts. This part of the work once done may be considered permanent or sufficiently durable to outlast more than a single generation.

2. Curbing, gutter pavement, fencing, guard rails, wooden bridges, concrete foundation, planting, etc., all of which may need periodical repairs, but will probably last twenty years at least.

3. The road surface, which will begin to deteriorate at once, and will need constant attention and periodical renewal."

"For each piece of work the records should include:

1. The character and first cost of the materials.

2. Cost of delivery on the work, with kind of transportation and distance hauled.

3. Cost of labor of all classes, with quality of same.

4. Cost or present value of plant and equipment, with allowance for depreciation due to the work under construction and not previously marked off.

5. All overhead charges, including engineering and inspection.

6. Cost of bonds, permits, etc.

7. All delays due to weather, failure to receive materials, strikes, or other causes.

8. A precise description of the methods employed and of the surface treatment of the road.

9. A statement as to the results obtained, the probable causes of failures or unsatisfactory work, and the means employed to correct or remedy them.

10. The manner in which the funds to pay for the work are raised, whether by cash appropriations, by the issue of bonds, with length of term and rate of interest, or by money advanced in anticipation of the collection of assessments for benefit."

In order to give some idea of the detailed information which

should be recorded if a complete record of a highway is to be kept, the construction and maintenance report forms used by the Special Committee of the American Society of Civil Engineers on "Bituminous Materials for Road Construction" are cited as illustrations of forms in current use.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

SPECIAL COMMITTEE ON
BITUMINOUS MATERIALS FOR ROAD CONSTRUCTION.

Please address reply to
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Committee:
W. W. CROSBY,
Chairman;
H. K. BISHOP,
A. W. DEAN,
A. H. BLANCHARD,
Secretary.

DATA CONCERNING THE USE OF BITUMINOUS MATERIALS IN ROAD SURFACING.

GENERAL INFORMATION.

State.......................... County..........................
Town.......................... Road..........................
Contractor..
Length of road..
Width of metal surfacing (average)..................................
Area of " " (total)..
Thickness of surfacing after rolling, with area of each
2".......... sq. yds.; 4".......... sq. yds.; 6".......... sq. yds.
8".......... " " ; 10".......... " " ; 12".......... " "
Amount of crown, maximum....... minimum..............................
Nature of subgrade (1)..
Percentage of grade (maximum) Length....... ft................ per cent.
" " " (minimum) " .... "................ " "
" " " (mean) (2) " .... "................ " "
Date of beginning of construction of metal surfacing.................
Date of completion of construction of metal surfacing................
Average rate of progress of construction of metal surfacing per working day.. sq. yds.
Average number of hours per working day....................... hours.

CLASS OF HIGHWAY OR NATURE OF TRAFFIC.

....
....

AMOUNT OF TRAFFIC OR TRAFFIC CENSUS FOR......HOURS (Average) (3).

Dates of census..............................

	Empty vehicles	Loaded vehicles	Est. (in lbs.) of maximum load per inch of tire	Passenger vehicles
Horse-Drawn Vehicle Traffic.				
One-horse vehicles	....	....	....	....
Two " "	....	....	....	....
Three " "	....	....	....	....
Four " "	....	....	....	....
Five " "	....	....	....	....
Six or more horse vehicles.........	....	....	....	....
Motor-Vehicle Traffic.				
Motor cycles...................	....	....	....	....
" runabouts...............	....	....	....	....
" touring cars (4 or 5 seats)....	....	....	....	....
" touring cars (6 or 7 seats) including limousines or landaulets............	....	....	....	....
" wagons or drays..........	....	....	....	....

FORM OF CONSTRUCTION.

(*i. e.*, macadam, gravel, sand or other surface, and whether treated with a bituminous material by mixing, penetration or other method.)

....

....

Artificial foundation: nature of (4)......................................

.................................; depth.......................

HAULING DISTANCES.

Average length of haul for gravel..................................miles.
" " " " " stone.................................. "
" " " " " sand.................................. "
" " " " " shells.................................. "
" " " " " bituminous materials.................... "
" " " " " binder or grit.......................... "
" " " " " ....
" " " " " ....

RATES OF LABOR (per day).

Foreman..................	$......;	Roller and engineer........	$......
Labor (ordinary)...........	......;	Water cart or sprinkler....	......
" (special)............	......;	Scarifier..................	......
One-horse team and driver...	......;	....	......
Two " " " " ...	......;	....	......
Three " " " " ...	......;	....	......

Equipment (5).

Rollers:— number......kind........weight..................tons
Water carts:— “ ...... “ ....capacity.................gallons
Oilers:— “ ...... “ .... “ .... “
Scarifiers:— “ ...... “ ....
....
....
Mixing plant..
....
....
Kettles and accessories...
....
....
Distributors...
....
....

Bituminous Material.

Kind of material..
Trade name..
Purchased from...
Shipped from..
Furnished by party of the first or second part..................................

Characteristics and Analyses (6).

	Tar compounds	Asphaltic compounds
Specific gravity..........................	....	....
Water soluble material (organic)..........	.....per cent.	.....per cent.
“ “ “ (inorganic)........	..... “	..... “
Free carbon....................................	..... “	..... “
Ash..	..... “	..... “
Solubility in cold carbon tetrachloride.....	....	..... “
Fixed carbon...................................	.....per cent.	..... “
Paraffine..	....	..... “
Melting point of normal material..........	.....degrees	.....degrees
Evaporation 5 hours at 170° C............	.....per cent.	.....per cent.
Melting point of residue..................	.....degrees	.....degrees
Penetration of residue at 4° C..........	....	....
“ “ “ at 25° C..........	....	....
Evaporation 5 hours at 205° C............	....	.....per cent.
Melting point of residue..................	....	.....degrees
Penetration of residue at 4° C..........	....	....
“ “ “ at 25° C..........	....	....

CHARACTERISTICS AND ANALYSES (6)—Continued.

	Tar compounds	Asphaltic compounds
Solubility in 88° B. naphtha..............	....	.....per cent.
Character of solution (oily or sticky).....	....	....
Distillation..........................	....	....
Up to 105° C.........................	.....per cent.	....
105° C. to 170° C.....................	..... "	....
170° C. to 225° C.....................	..... "	....
225° C. to 270° C.....................	..... "	....
270° C. to 300° C.....................	..... "	....
Viscosity 100° C. (7)...................	....	....
Engler viscosimeter....................	.....seconds	.....seconds
Lunge tar tester......................	..... "	..... "
Penetrometer..........................	....	....
New York Testing Laboratory viscosimeter	....	....
Viscosity 25° C. (7)....................	....	....
Engler viscosimeter....................	.....seconds	.....seconds
Lunge tar tester......................	..... "	..... "
Penetrometer..........................	....	....
New York Testing Laboratory viscosimeter	....	....
....	....	....
....	....	....

CONSTRUCTION DATA.

Amount of bituminous material used per sq. yd. (in gals.).
First course.................. second course.....................
Surface coat................ total...........................
Temperature to which material was heated.
First course.......... second course........ surface coat..........
Temperature of air during use of bituminous material.
Maximum.......... minimum........... mean..............
Date of beginning of use of bituminous material.......................
Date of completion of " " " " ....
Average rate of progress of using bituminous material (per day in gallons).
First course.......... second course........ surface coat..........
General weather conditions during use of material.......................
Cost, f. o. b. cars, of bituminous materials (per gallon)..................
Freight on bituminous materials (per gallon)...........................
Cost of loading and hauling bituminous materials (per gallon)..............
Total cost delivered on road of bituminous materials (per gallon)..........
Cost of heating " " " " ....
Cost of spreading or mixing " " " " ....
First course.......... second course........ surface coat..........
Total cost in place of bituminous materials (per gallon)..................
" " " " " " " (" sq. yd.)..................
Contract price in place of bituminous materials (per sq. yd.)...............

METAL SURFACING.

	Telford or other base.	1st Course.	2nd Course.	Binder or grit.	Totals.
Name (8) of material used	....	....	....	....	....
Abrasion test (9) of material used	....	....	....	....	....
Absorption test of material used	....	....	....	....	....
Fracture (10) of material used	....	....	....	....	....
Crushing strength of material used (lbs. per sq. in.)	....	....	....	....	....
Thickness after rolling of material used	....	....	....	....	....
Size (11) of material used..	....	....	....	....	....
Amount (in tons) or cu. yds. (12) of material used	....	....	....	....	.....
Cost, f. o. b. cars, of material used, per ton or cu. yds. (12)	....	....	....	....	....
Freight on material used, per ton or cu. yds. (12) . .	....	....	....	....	....
Cost of loading and hauling material used, per ton or cu. yds. (12)	....	....	....	....	....
Total cost delivered on road of material used, per ton or cu. yds. (12) . .	.....	....	....	....	....
Total cost delivered on road of material used, per sq. yd	....	....	....	....	....
Cost of scarifying and shaping old surface, per sq. yd	....	....	....	....	....
Cost of laying or spreading of material used, per sq. yd	....	....	....	....	....
Cost of watering and rolling of material used, per sq. yd	....	....	....	....	....
Total cost in place of material used, per sq. yd	....	....	....	....	......
Contract price in place of material used, per sq. yd.	....	....	....	....	....
....	....	....	....	....	....
....	....	....	....	....	....
....	....	....	....	....	....

REMARKS.

....

....

NOTES AND EXPLANATIONS.

(1) In stating "nature of subgrade" note whether sandy, clayey, loamy, or otherwise, and whether readily and thoroughly compacted by rolling.

(2) "Mean" percentage of grades to be obtained by multiplying length of grade by its per cent., adding all products together and dividing by total length.

(3) If possible "average" should be arrived at from two or three separate determinations. State number of determinations from which "average" is secured.

(4) After "Artificial Foundation, nature," sufficient information should be inserted to indicate whether simply a layer of gravel is used, and nature (sandy or otherwise) of same; or whether a foundation is laid by hand of large stone; or whether a layer of crushed stone is rolled into the subgrade before commencement of surfacing proper.

(5) Under "Equipment" should be stated any charges paid as rentals.

(6) For methods of determination of characteristics listed, see enclosed "List of Analyses and Methods of Testing Bituminous Materials" proposed by Committee.

(7) In reporting "Viscosities" of course figures can only be given in terms of the one (or more) instruments applying in any case.

(8) Give, if possible, geological "name" of material used in each course. Reference, "Rocks," by Kemp.

(9) "Abrasion test" should be stated in terms of French coefficient of wear.

(10) "Fracture" should be stated as "cubical" or "scaly."

(11) "Size" should be stated as maximum and minimum of sizes of openings in screens to pass and hold stone used.

(12) Cross out unit not used.

Name..

Title...

Address.....................................

....

....

Reporting Officer.

Date......................, 19....

AMERICAN SOCIETY OF CIVIL ENGINEERS.

SPECIAL COMMITTEE ON
BITUMINOUS MATERIALS FOR ROAD CONSTRUCTION.

Please address reply to
A. H. BLANCHARD,
Secretary,
Columbia University,
New York City.

Committee:
W. W. CROSBY,
Chairman;
H. K. BISHOP,
A. W. DEAN,
A. H. BLANCHARD,
Secretary.

To.....................................

....

....

The Committee again acknowledges its indebtedness for co-operation in reporting on the construction of roads, in connection with which bituminous materials were used. The information furnished is of great value, but in order to make it more fully available it seems advisable to request the supplementary information on the points covered by the following form.

The general information previously furnished has been filled in by the Secretary.

It is the intention of the Committee to ask annually for reports, each to cover a year of observation, and it is hoped that this form will be returned as soon as data covering a year are available.

Report on Results of the Use of
BITUMINOUS MATERIALS IN ROAD CONSTRUCTION.

GENERAL INFORMATION.
(Required for identification with previous reports.)

State.............................County.............................
Town.............................Road.............................
Contractor...
Kind of bituminous material..
Trade name...
Method...
Dates between which work was done.............to...................

PERIOD COVERED BY THIS REPORT.

From.............................to.................................

CLASS OF HIGHWAY OR NATURE OF TRAFFIC.

....

....

Amount of Traffic or Traffic Census for........Hours (Average)*

Dates of census..

	Empty vehicles.		Loaded vehicles.		Est. (in lbs.) of maximum load per inch of tire.		Passenger vehicles.	
	Nov. to March.	Apr. to Oct.	Nov. to March.	Apr. to Oct.	Nov. to March.	Apr. to Oct.	Nov. to March.	Apr. to Oct.
Horse-Drawn Vehicle Traffic.								
One-horse vehicles...	......	......	......	......	......	......	......	......
Two " " ...	......	......	......	......	......	......	......	......
Three " " ...	......	......	......	......	......	......	......	......
Four " " ...	......	......	......	......	......	......	......	......
Five " " ...	......	......	......	......	......	......	......	......
Six or more horse vehicles..........	......	......	......	......	......	......	......	......
Motor-Vehicle Traffic.								
Motor cycles........	......	......	......	......	......	......	......	......
" runabouts....	......	......	......	......	......	......	......	......
" touring cars (four or five seats)......	......	......	......	......	......	......	......	....
" touring cars (six or seven seats) including limousines or landaulets.....	......	......	......	......	......	......	......	......
" wagons or drays......	......	......	......	......	......	......	......	......

* If possible, "average" should be arrived at from two or three separate determinations. State number of determinations from which average is secured.

(1) Date of opening road to traffic, or average length of time after completion before sections of road were opened to traffic.

(2) Has the surface begun to disintegrate? If so, when and in what manner? What was the probable cause?

(3) Has any displacement of the surface been manifest in the shape of ruts, waves, etc.?

(4) Was the surface objectionably soft in hot weather? If so, state air temperature; also state maximum temperature at which surface was satisfactory.

(5) Is the tractive effort increased by the presence of the bituminous material?

(6) Was the surface slippery for horses or motor cars in (1) cold weather, (2) when wet, (3) on frosty mornings?

(7) Are the stones of the top course of the macadam visible? If so, to what extent?

(8) Has the surface worn differently adjacent to curbs and car rails than it has in the traveled ways?

(9) During what period covered by this report was the surface coated with snow or ice?

(10) Maximum depth of frost in this period.

(11) Amount of rainfall for the period covered by this report.

(12) Has the surface been artificially watered? If so, to what extent?

(13) Has surface been cleaned? If so, to what extent?

(14) Is road shaded or exposed?

(15) Cost and character of maintenance during period covered by this report.

(16) Your general opinion on the results secured on the above road and any information not covered properly by the above is desired.

(PLEASE WRITE ANSWERS TO FOREGOING QUESTIONS, REFERRING TO EACH BY NUMBER.)

....

....

Name...

Title...

Address..

....

....
Reporting Officer.

Date....................191....

CHAPTER XXV

SIDEWALKS, CURBS, AND GUTTERS

The design and construction of sidewalks, curbs, and gutters constitute an important part of the work of a highway engineer.

Sidewalks

Essential Qualities. There are several essential qualities which a sidewalk should possess. The surface should be smooth but not slippery, non-porous, agreeable in color, cheap, easy to clean, and constructed of a material which will wear well. When used on a business street the material should be sufficiently strong to resist the shocks from falling bodies and of such a character that repairs can be easily made.

Width of Sidewalks. Sidewalks in business districts usually extend from property lines to curbs. In residential districts this same arrangement may be used or a space for a grass plot or row of trees may be left between the edge of the sidewalk and the curb. In some cases on roads the walk is entirely omitted or restricted to a narrow footworn path on the side of the highway. The widths of sidewalks from property line to curb vary from 6 to 20 feet, the usual width for each sidewalk being from one-fifth to one-sixth of the distance between property lines. For a further discussion of the relation of the width of sidewalk to width of street see Chapter IV.

Slope of Sidewalks. It is essential that sidewalks be pitched so as to shed the water which falls upon them. This is generally accomplished by sloping the walk from the property line to the curb by an amount varying from $\frac{1}{8}$ to $\frac{1}{2}$ inch per foot, depending upon the kind of material with which the surface of the walk is constructed. In some cases the high point of the walk is made near the center and the surface is pitched both

ways. This arrangement, however, has the disadvantage of throwing part of the water towards the property, of being objectionable in appearance and uncomfortable to walk upon, if the crown is too high.

Materials. Construction. Cost Data. The materials used in the construction of sidewalk surfaces are artificial flags, asphalt mastic, brick, cinders, cement-concrete, gravel, small stone sets, stone flagging, tar-concrete, tile and various artificial preparations. The construction of several of the above types will be briefly described, and in order to make the presentation clear each type will be considered separately.

Asphalt Mastic. This type of pavement is constructed in France by preparing a mastic from a combination of rock asphalt and a refined asphalt fluxed with an asphaltic base petroleum. Sufficient fluxed asphalt is mixed with the powdered rock asphalt so that the mixture will contain 20 percent of bitumen. A layer of this mixture of about 1 inch in thickness is placed on a cement-concrete foundation which is about 4 inches in thickness and has been covered with a layer of cement mortar from ½ to 1 inch in thickness. A scattering of gravel is spread on the surface and gently rolled into the asphalt mastic while the latter is still warm.

Cost. The average cost of this pavement in France is approximately $1 per square yard. The cost of a similar pavement in England is about $1.43 per square yard.

Characteristics. Footways constructed with an asphalt mastic have a great many points of excellence. They are practically non-absorbent, very smooth, without joints, pleasant to walk upon, easily maintained and repaired. It is also an easy matter to finish the surface around castings and openings which must be kept in the walk. A thickness of mastic of ¾ of an inch will last from five to ten years and sometimes longer on streets where the traffic is not particularly heavy.

Brick and Tile. The bricks or tile used in sidewalk construction are usually made of burned clay, although tile made of compressed asphalt is used to some extent. Frequently the surfaces of the brick or clay tile are stamped in the process of re-

pressing with some figure of fancy design, for the purpose of adding to the appearance of the finished walk. In France the usual size of tiles used is 5 to 5½ inches square and 1¼ to 1½ inches thick. In the Netherlands the brick are 7 inches long by 3½ inches wide by 2 inches deep. In the United States bricks of the ordinary building size are frequently used. Brick sidewalks to be successful should be given the same care in constructing them as is accorded a brick pavement. The best results will be obtained if the bricks are laid on a thin sand cushion, about 1½ inches in depth, which is spread over an accurately surfaced concrete foundation, 4 inches thick, and the joints are filled with a bituminous filler. The bricks are usually laid flat rather than on edge, and with their longest dimensions either at right angles or diagonally to the curb line. Another popular arrangement is to lay the bricks by the so-called herring-bone method, shown in Fig. 178. Frequently brick sidewalks are laid on a bed of sand placed in an earth trench and the joints filled with sand. It is not surprising to find that a brick sidewalk constructed in this manner soon loses its shape due to the displacement of

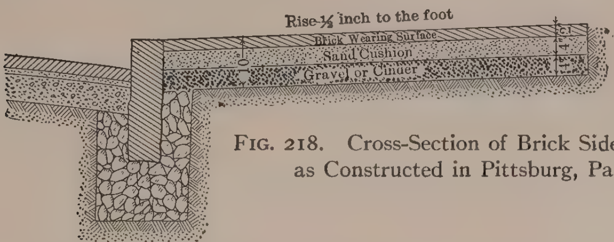


FIG. 218. Cross-Section of Brick Sidewalk as Constructed in Pittsburg, Pa.

the bricks. If a concrete foundation is not used a foundation of good gravel or cinders should be employed underneath the sand cushion. This type is shown in Fig. 218, which is the standard brick sidewalk as constructed in Pittsburg, Pa.

Cost. The cost of tile paving in England, the size of the tiles being 10 inches by 5 inches by 2½ inches, is $1.62 per square yard. The cost of constructing tile pavements in France of a size as was mentioned above, the tiles being bedded in mortar and the joints filled with mortar, varies from $1.30 to $1.50 per

square yard. The cost of brick sidewalks in Holland, the bricks being laid in a sand bed on a concrete foundation about 4 inches thick and the joints filled with a cement grout, is about 87 cents per square yard. In the United States the cost of brick sidewalks on a 4-inch concrete foundation with a bituminous filler is about $1.75 per square yard.

Characteristics. When properly constructed, brick sidewalks are very satisfactory. They are not slippery, they wear well, are easy to repair, are comfortable to walk upon when smooth, and are easily cleaned.

Cinders. Cinder sidewalks are built in Chicago by depositing the cinders in three layers, the first layer being 9 inches deep and composed of coarse material, the second layer 3 inches deep and composed of fine cinders, and the third layer fine cinders in sufficient amount to form a crown to the surface. Each layer is thoroughly tamped or rolled. Cinder sidewalks may be built very cheaply and make a satisfactory surface in outlying districts. It is also possible to use the cinder sidewalk as a foundation for some other type of surface at a later date.

Concrete. Cement concrete sidewalks have become popular in the United States during the past few years and at the present time this material is used for constructing sidewalks more than any other. In business districts where vaults are constructed beneath the sidewalks, the surface is frequently composed of reinforced concrete slabs in which are placed plate glass shapes for the purpose of lighting the vault below.

The Concrete. The concrete is a mixture of Portland cement, sand and broken stone, gravel or slag. The 1912 specifications of the Association for Standardizing Paving Specifications stipulate that:

"The fine aggregate shall consist of any material of siliceous, granitic, or igneous origin, free from mica in excess of 5 percent, and other impurities, and shall be of graded sizes ranging from ¼ inch down to that which shall be retained on a No. 100 standard sieve, not more than 20 percent of which will pass a No. 50 standard sieve for the base; and from ¼ inch down to that which will be retained on a No. 80 standard sieve, nor more than

20 percent of which shall pass a No. 50 standard sieve for the top or wearing surface.

"The coarse aggregate shall be sound gravel, broken stone or slag having a specific gravity of not less than 2.6. It shall be free from all foreign matter, uniformly graded and of sizes that will pass a 1-inch screen and be retained on a ¼-inch screen.

"In preparing the concrete for the base, the cement and aggregate shall be measured separately, and then mixed in such proportions that the resulting concrete shall contain fine aggregate amounting to one-half of the volume of the coarse aggregate; and that 5½ cubic feet of concrete in place will contain 94 pounds of cement. The top or wearing surface shall be composed of one part Portland cement and two parts fine aggregate, mixed with sufficient water to produce a mortar of a consistency which will not require tamping, and which can be easily spread into position with a straightedge."

Subgrade. Concrete sidewalks should be provided with a well drained foundation. The depth of excavation to the subgrade will depend upon the climatic conditions and the nature of the ground. In places where frosts occur, it may be necessary to excavate the ground for a depth of 12 inches or more, whereas in places where there are no frosts, 4 to 6 inches will be sufficient. As is the practice in the construction of pavements, the subgrades are given a transverse slope towards the gutter, which in this case is about ¼ inch to the foot. Care should be taken in completing the subgrade that the material is thoroughly compacted and that all soft and defective places are removed and filled with good material. Boulders, tree roots, etc., should be carefully removed. When the subgrade is constructed on a fill instead of in excavation, extreme care should be taken to make sure that there will be no further settlement of the embankment. On the completed subgrade is built a subbase, the thickness of which may be 12 inches or more in cold climates and 2 or 3 inches in some cases where the soil conditions are particularly favorable. A material which is largely used for a subbase is cinders. Broken stone, sand, gravel, slag, and other materials of a clean and hard nature are also used. Many

times in reconstructing old tar concrete sidewalks the old surface is broken up and put into the subbase. The subbase should be thoroughly compacted. In using such materials as cinders or sand, they should be wet down during the process of ramming or rolling. In some cases it may be advisable to drain the subbase. This is accomplished by either laying tile drains or blind stone drains to the curb foundation.

Placing the Concrete. The concrete is usually deposited in two layers, a base layer and a wearing surface. The ingredients of which these two layers are composed have been previously described. The thickness of the two courses will depend upon the traffic conditions, the climatic conditions, and whether or not the sidewalk is situated in a place where heavy goods are handled on it. A minimum total thickness of concrete is usually put at 3½ inches, made up of a base course 3 inches thick and a wearing surface ½ inch thick. In cases where the traffic con-

FIG. 219. Cross-Section of Cement-Concrete Sidewalk as Constructed in Pittsburg, Pa.

ditions are severe or there is much frost, the total thickness may be made as much as 6 inches, the wearing surface being from 1 to 2 inches thick. The standard construction in residential districts of Pittsburg, Pa., is shown in Fig. 219.

The general principles relative to mixing, handling, and placing concrete which have been previously mentioned in Chapters VI and XIX apply as well to the concrete used in sidewalk construction. There are a few points, however, which are peculiar to this method which should be mentioned. The concrete should never be laid as a monolithic mass unless reinforced with steel, but should be divided into separate sections by joints extending through the full depth of the concrete. The correct size of slabs has been found to be one which does not

contain over 36 square feet of surface and is not over 6 feet in any one direction. The sections are obtained by constructing either wooden or steel forms on the subgrade corresponding in shape and size to the section desired. The forms must be well braced and of sufficient rigidity so as to resist springing out of shape as the concrete is placed in them. The cross forms or those which come on the lines of the joints between adjacent slabs are preferably made of ¼-inch metal and of a depth corresponding to the full thickness of the proposed walk. When metal cross forms are used the slabs may be built up to a form on each side, and when the concrete has set the metal strip may be withdrawn. When wooden cross forms are used every other slab is built, and after completion the cross forms are removed and the other sections are placed. The joints are formed by laying pieces of tar paper against the faces of the slabs first constructed.

The concrete for the base course should be thoroughly tamped in the forms until the required thickness is obtained. Before the concrete in the base course sets up the wearing surface should be spread on it. The concrete in the wearing surface is mixed wetter than that in the base course. It is shaped and spread by means of a straightedge, the ends of which generally rest on the forms. The surface is then smoothed out with trowels or a wooden float. To roughen the surface a little sand may be scattered over it and worked in during the process of smoothing. A soft brush may be used to mark the surface or some form of grooving tool may be employed. Traffic should be barred from the sidewalk for a week, during which time the surface should be frequently moistened. The surface should also be covered with a tarpaulin or otherwise for the first day or two after completion.

Cost. The cost of cement concrete sidewalks, including excavation and a cinder or gravel foundation, varies from about 80 cents to $1.50 per square yard. H. P. Gillette, M. Am. Soc. C. E., states that the average cost of a number of small jobs was distributed as follows:

	Cost Cts. per sq. ft.
Excavating 8 inches deep at \$0.27 per cu. yd.......	0.65
Gravel for 4-inch foundation at \$1.00 per cu. yd....	1.20
0.018 bbl. cement at \$2.00......................	3.60
0.009 cu. yd. broken stone at \$1.50..............	1.35
0.006 cu. yd. sand at \$1.00......................	0.60
Labor making walk	1.60
Total............................	9.00

"The walks were built 4 inches thick with a 3-inch base course of 1 : 3 : 6 concrete and a 1-inch wearing surface of 1 : 1½ mortar. The gangs that built the walks were usually

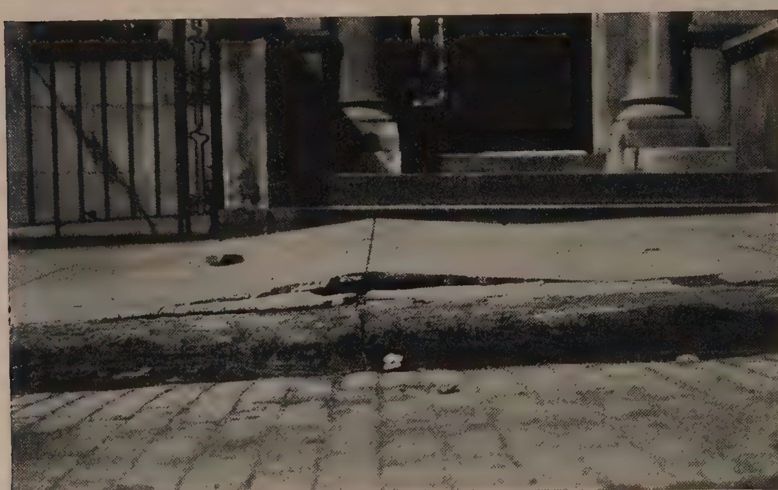


FIG. 220. Bulging of Cement-Concrete Sidewalk, due to Expansion.

two masons at \$2.50 each per ten-hour day with two laborers at \$1.50 each. Such a gang averaged 500 square feet of walk per day."

Characteristics. Concrete possesses several advantages as a sidewalk material. In the first place, the materials with which it is constructed are available in many localities. It makes a durable surface if properly constructed, is not slippery under normal conditions, is easily cleaned, is more or less impervious to water, and its cost is not excessive. Concrete also possesses the

advantage of being easily moulded in any form desired. Moreover, it is possible to incorporate coloring matter in the concrete so as to obtain a variety of different colors. When constructed in conjunction with a curb and gutter built of the same material, it gives the street a finished appearance which is hard to obtain with other materials.

Concrete pavements fail many times by the slabs bulging upward, caused frequently by the heaving action of the frost

FIG. 221. Longitudinal Crack in Cement-Concrete Sidewalk, due to Frost Action.

or because the slabs have been pushed up by the roots of trees, or it may be due to poor workmanship where sufficient allowance has not been made for expansion. The photographs shown in Figs. 220 and 221 illustrate this type of failure. The slabs may be cracked through in this condition or the bulging may occur so that the heaving all takes place at a joint between two adjacent slabs without breaking them. Unequal settlement will also cause the slabs to be displaced, and if too great for the strength of the slabs they will crack.

Gravel. Gravel walks are laid 3 to 4 inches thick on a good subsoil. Where the soil is poor it is excavated and the space

refilled with crushed stone, clinker, or screened gravel of large size. The total depth may be as much as 8 inches, the wearing course being ¼ to ½ inch of fine gravel or torpedo sand.

Small Stone Sets. Small stone set sidewalks are constructed in many towns of Portugal in which small stones are laid in arcs of circles or conforming to figures of fancy design. Different colored stones are used, which give a contrast in color very pleasing to the eye. In Germany, Kleinpflaster is used to a considerable extent for sidewalks.

Stone Flagging. Sidewalks in business districts are frequently constructed of stone flagging. Stone flagging will also be found used as a surfacing for sidewalks in residential districts in different parts of the United States where this stone is available. Granite and sandstone are the common materials from which the slabs or flagging are made in this country. Granite slabs 6 inches thick are laid in Paris for sidewalks on some of the principal streets which carry a heavy foot traffic. Flagging of Yorkshire or Caithness stone is very popular throughout certain parts of England. Artificial flagging made of concrete under pressure has also been used to a slight extent.

The Stone. The 1912 specifications of the Borough of the Bronx, New York City, require that new flagstones shall be of a good quality of sandstone (bluestone), with a fairly smooth surface, and shall measure not less than 4 feet in width, contain not less than 10 square feet, except where necessary to fit around basin heads, and shall be uniformly not less than 3 inches in thickness. The Yorkshire flagging used in England is generally required to be ½ inch thick for every square foot of surface and of such a size that there will not be more than fourteen slabs to make 100 square feet. Artificial flagging is made in slabs from 2 to 4 feet square.

Laying the Stone. The following quotation from the Borough of the Bronx specifications, previously referred to, describes the method of constructing flagstone sidewalks in that locality.

"New flagging shall be laid with close joints, in regular courses of not less than 4 feet in width, and each stone shall be so dressed on the joints that all feather edges and drill or tool

holes are removed. It shall be bedded in earth, free from vegetable matter, and the work brought to an even surface, with such pitch as may be directed and conforming with the grade of the street. The joints of the flagging shall be filled with cement mortar consisting of one part Portland cement and four parts sand, and be left clean on the surface. The courses of bluestone flagging shall be laid or trimmed to parallel sides, and in measurement no allowance will be made for any excess in width over 4 feet." Fig. 222 shows a cross-section of the standard method of constructing flagstone walks in Pittsburg, Pa. In England

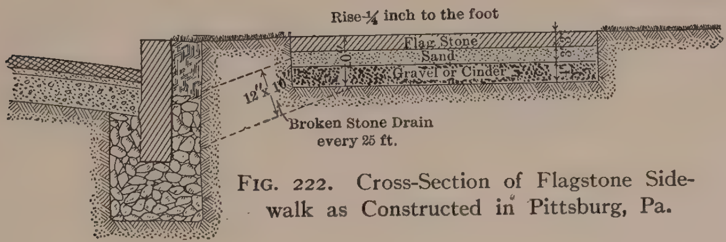


FIG. 222. Cross-Section of Flagstone Sidewalk as Constructed in Pittsburg, Pa.

both the natural and artificial flagging is bedded on a layer of lime mortar which rests on a 2- to 3-inch course of clinkers. The joints are made flush and are filled with a cement mortar. The granite slabs used in Paris are generally bedded on a concrete foundation.

Cost. The cost per square yard of one type of artificial flagstone paving in Croydon, England, was $1.68. In France the granite sidewalks constructed as mentioned above cost from $3 to $3.60 per square yard. In New York City the cost of bluestone sidewalk flags from the Hudson River, laid in place, varies from $1.66 to $2.20 per square yard. The cost of walks built with the same material in Boston per square yard varies from approximately $2.50 to $3.00.

Characteristics. The life of granite slab sidewalks, if constructed on a proper foundation, is practically indefinite. The surface wears smooth in time, but it may be easily roughened by means of a tooth axe. An objection to granite slabs is that they are extremely heavy to handle and their cost is rather high.

There are many instances in England where flagstone sidewalks have lasted from twenty-five to thirty years. The sidewalks constructed with bluestone flagging in this country are generally quite satisfactory, except that in many instances the flags are displaced by frost action or other causes.

Tar Concrete. Tar concrete sidewalks are constructed in many places in the United States and England.

Laying the Concrete. This type of surface is constructed generally in two or more courses, the materials in the different courses varying in size. In Newton, Mass., a three-course method is used, the different courses being described as foundation course, binding course, and wearing surface. The foundation course is composed of coarse gravel from 2 to 4 inches in greatest diameter, thoroughly coated with hot tar. The binding course is composed of clean screened gravel not exceeding 1 inch in greatest diameter, which is heated and mixed with a hot coal tar composition in an amount of about 1 gallon of the bituminous material to 1 cubic foot of gravel. The wearing surface is composed of screened sharp sand, which is heated and mixed with a coal tar composition, the mixture consisting of not more than 75 percent of sand and not less than 25 percent of the bituminous material by weight. The surface is laid to a total depth of 3 inches. Each course as it is laid is thoroughly tamped and rolled. The binding course fills the voids in the foundation course to a large extent. The total thickness of these two courses, after compaction, is not less than 2¼ inches. The wearing surface, which is ¾ of an inch thick, is laid and rolled in a similar manner. The top surface is usually sprinkled with a fine sand or a Portland cement, which is well rolled.

Cost. The cost of tar concrete sidewalks in the United States is approximately $0.60 per square yard. The cost of this type of sidewalk in England, constructed by a method very similar to that just described, is about $0.62 per square yard.

Characteristics. Tar concrete sidewalks usually are not slippery. If the bituminous material is of the proper consistency the surface is rather elastic and pleasant to walk upon. The use of a bituminous material not possessing the proper characteristics

may result in cracks being formed in the surface in cold weather, with consequent disintegration of the pavement, or in warm weather the tar compound may soften to such an extent that the surface becomes objectionable to walk upon. The surface is easily cleaned when intact and is also one which may be easily repaired. Its low cost has led to its general use in many places, although at the present time it is being replaced to a considerable extent by cement concrete.

Curbs

Curbs are constructed of either stone or cement concrete. Of the stones, granite, limestone, and sandstone are used, granite and sandstone perhaps being most commonly employed.

Stone Curbs. Stone curbs are made from 4 to 12 inches wide, 8 to 24 inches deep, and from 3 to 8 feet long. The top and front faces are dressed, the latter being given a slight batter for a depth somewhat greater than the exposed part, to keep the wheels away from the top edge. The ends are square dressed and the curbs in first-class work are so laid that the ends come about ⅛ inch apart. The specifications of the City of Baltimore for 6-inch granite curb require that "the curbstone must have a uniform thickness of 6 inches, a depth of not less than 20 inches, and to be in lengths of not less than 8 feet, the top to be bush dressed to a true surface, the faces to be dressed to a depth of 14 inches from the top, 9 inches of which, from the top downward, shall be bush hammered and the balance of 5 inches pointed down so as to leave no lump or projection of more than ¼ of an inch. The back shall be pointed to a depth of 3 inches from the top, with draft on the edge. All joints must be fine point dressed square to the top for the full depth of the stone."

Laying the Curb. Curbstones, although commonly laid on a well compacted sand base, should be laid on a base of concrete, broken stone, or gravel. The broken stone or gravel is carried well up around the base of the curb, as shown in Fig. 219. The trench should be made wide enough to permit thorough ramming. In Baltimore a bed of gravel 4 inches deep is laid on the bottom of the trench and is well compacted. The curb is laid on this

bed and set to the line and grade. The remainder of the trench is filled with layers of well compacted gravel.

Cost. The cost of a granite curb, including the cost of setting, is about $1.00 per linear foot.

CONCRETE CURBS. The curbs are generally built in situ, although it is possible to make them at some central point and ship them when required.

Construction. The curbs in either case are made approximately 6 inches thick, 18 to 24 inches deep, and from 8 to 10 feet in length. The proportions of the different materials used in the concrete are the same as those described for concrete sidewalks. The corner next to and above the gutter is always moulded to a radius approximating 1½ inches in length. Sometimes this corner is formed by a metal strip, having the desired radius of the corner, which is built into the curb at the time the concrete is being laid. The strip is anchored to the body of the curb at three or four points in each length of 8 to 10 feet by special forms of steel tie bars that are firmly attached to the metal strips. The protection afforded the edge of the curb by this metal strip is of a decided advantage. The concrete curb and a concrete gutter are sometimes constructed as one piece, in which case the depth of the curb is somewhat less than that described above, as the base of the curb is flush with the base of the gutter, see Fig. 223.

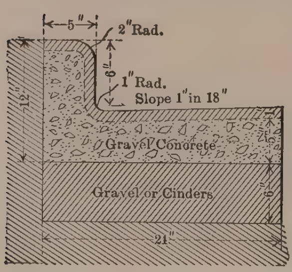


FIG. 223. Concrete Curb and Gutter.

A concrete curb should be constructed on a bed of well compacted sand, gravel or cinders, in the same manner as described for stone curbs. The joints between adjacent curbs are made by placing metal plates, of the thickness of the joint desired, in the forms at the end of each curb length. The concrete is filled in to the plates, and after it has obtained its initial set the plates are withdrawn, thus leaving a joint. When the curbs are built at the same time as the sidewalk surface, an expansion joint should be left between the sidewalk and the curb. The same remarks

which have been stated relative to handling the concrete and forms in the case of concrete sidewalks apply as well to the construction of curbs.

Cost. The cost of concrete curbing 8 inches wide by 24 inches deep in one instance was approximately 30 cents per lineal foot, including the cost of laying. In certain cities of Iowa the cost of constructing combined curbs and gutters of concrete, generally built on a 4- to 6-inch foundation of cinders or gravel, varied from about 60 to 80 cents per lineal foot. The cost of straight curb of concrete in one locality was about 37 cents per lineal foot. H. P. Gillette, M. Am. Soc. C. E., gives the following detailed cost data of constructing a combined concrete curb and gutter on a 6-inch cinder foundation. The curb was about 12 inches deep and 5 inches thick, the gutter being 19 inches wide from the face of the curb and about 6 inches thick:

	Cost per 100 feet
Trenching	$ 2.43
Placing and tamping cinders	1.00
Setting forms	1.69
Mixing, placing, and finishing concrete	7.64
Portland cement, $8\frac{1}{3}$ bbls., at $1.85	15.42
Cinders, 7.5 yards, at 50 cents	3.75
Gravel, 2.5 yards, at $1.00	2.50
Broken stone, 2.5 yards, at $1.40	3.50
Sand, 1 yard, at $1.00	1.00
Total materials and labor	$38.93
Contractor's profit	6.00
Grand total	$44.93

The above shows that the cost per lineal foot was about 45 cents. In 100 lineal feet of curb and gutter there were 4.6 cubic yards of concrete and mortar facing, 4 cubic yards of which were concrete.

Gutters

As a general rule paved gutters are not constructed along the sides of roads outside of built-up districts unless it is on grades

where there is danger of wash-outs. The water is carried in the side ditches, the construction and arrangement of which have been described in previous chapters. Some form of paved gutter may, in some cases, be considered a requisite for successful construction on steep grades. On streets which are curbed and which have the carriageways constructed with some kind of improved surfacing, it is always essential to construct a paved gutter for several reasons. Traffic uses the whole width of surface from curb to curb, hence if some form of paved gutter were not built, it is self-evident what the condition, during wet weather, of the street would be between the edge of the pavement and the curb. The paved gutter protects the edge of the pavement and the curb and prevents the surface water from accomplishing the harm that would probably ensue if it were not constructed.

Materials. Gutters are constructed of a variety of materials, among which may be mentioned brick, stone block, cobblestone, cement-concrete, small rubble stone, and any of the pavements, such as brick, stone block, wood block, sheet asphalt, or any other type of bituminous pavement, which form a continuation of the surfacing of the adjacent carriageways. Cobblestone and small rubble stone are extensively used in constructing gutters in the case of country highways. Cobblestone, cement-concrete, and brick gutters are also frequently built adjacent to macadam surfaces in city streets. Brick gutters are also very popular in some cities where bituminous concrete pavements are built.

Construction. Although stone block, cobblestone, rubble stone, cement-concrete, and brick gutters are sometimes constructed with the same transverse slope as the adjoining surface of the carriageway, since the principal object of the gutters is that of carrying the surface drainage, it is better to increase their water-carrying capacity by either building them on a sharper slope or by building the gutter with a concave curve section. The depth of the gutter at the center of the curve varies from 4 to 9 inches, depending upon the width and grade of the gutter. These gutters are built from 2 to 6 feet in width, depending upon the amount of water to be carried, 3 to 4 feet being widths used under ordinary conditions. Where no curb exists the edge of

the gutter farthest away from the pavement is sometimes carried up the slope of the bank for a distance of 1 to 2 feet as a further protection and also to increase the capacity of the gutter. Cobblestone, rubble stone, cement-concrete, and brick gutters are commonly constructed on a foundation of sand, gravel or cinders, the joints being filled with sand or poured with a cement grout. On city streets a concrete foundation is frequently built under a brick gutter. Since the cost data of gutters is the same as that of the different types of paving of which they are composed, information in regard to cost may be found in the chapters describing the construction of the various pavements.

CHAPTER XXVI

BRIDGES, CULVERTS, AND GUARD RAILS

Determination of Waterway. The first step in designing a bridge or a culvert is to determine the size of opening necessary to take the water. The practice of basing this determination on a mere guess should be condemned, since it will usually result in an uneconomical design or a wash-out, which, in the case of structures of any size or importance, may involve loss of life and property. The proper size of opening for a culvert or bridge cannot be determined by measuring the cross-section of the water at the point where the bridge or culvert is to be located unless the water at the time happens to be at its maximum stage. There are various ways, however, in which the amount of water and size of opening can be determined. The variables which enter into the problem make the results more or less approximate, and different formulas or methods may give widely varying results for the same conditions. In any event the use of such results is better than a mere guess, and if some method or formula be applied to conditions in any one locality for a sufficient length of time, and proper study be given to the factors which tend to make the results approximate, in time the method or formula can be depended upon to give results which, for that particular locality at least, are reasonably accurate. The following methods are used in determining the size of opening or the amount of water for which provision must be made:

Empirical formulas, which give either the area of opening or amount of water.

Observation of high-water marks.

Measurement of the flow.

There are several factors which affect the amount of water that will come to any particular point, among which may be mentioned the size of the drainage area, its topography, its

shape, and the soil conditions throughout the area, whether sandy, rocky, grass land, or covered with forests; the amount of rainfall and its intensity, that is, the rate at all periods throughout the storm; storage conditions, climatic conditions which govern evaporation, snowfall and ice, and the direction which storms take, whether along or across the streams. It is apparent in considering the above factors that the problem is not one capable of being solved by a definite formula free from assumptions.

Size of Drainage Area. Since the size of the drainage area enters into practically all of the calculations required, its determination will be considered before discussing the various methods of finding the size of opening. Every drainage area is separated from an adjacent drainage area by a divide or a line of high ground. The drainage area for a culvert or a bridge will therefore include all of the area above the structure bounded by the line of the divide. The drainage area may be determined by actual measurement in the field or from a map. The field survey may be made by running a traverse line around the boundary with a transit and stadia, or a pocket compass may be used to obtain the direction of the boundaries while the distances may be paced. Extreme accuracy is not essential. If government topographical maps made by the geological survey are available, the drainage area can be marked off by tracing out the divides from the contours and the area be determined by planimeter or by scale. Any other good contour map of the locality will do exactly as well. Besides the actual size of the area, however, it is necessary to know the steepness of the slopes and the nature of the soil conditions, because these factors affect the run-off to a great extent. Such information can generally be determined only by examination.

Empirical Formulas. Empirical formulas are many in number and give results which are extremely variable. This may be accounted for in some instances by the fact that the formulas were calculated for conditions in some one locality that do not agree with those in another. Again, some of these formulas have only one variable in them, namely, the drainage area, and it cannot be expected that results by such formulas will agree

with those obtained by formulas which have coefficients that are to be applied for different soil conditions, steepness of slope, etc.

Myers Formula. One formula which is used to a great extent by railroad engineers in the eastern part of the United States is the Myers formula or $A = C\sqrt{D}$, in which A is the area of waterway in square feet; D is the drainage area in acres; C is a variable coefficient, being 1 for comparatively flat ground, 1.6 for hilly compact ground, and 4 for mountainous, rocky country. The Myers formula has been found to give areas for small openings that are somewhat large, which is not a serious criticism. On the other hand, it appears that this formula does not give sufficient area for large openings, but in defense of this criticism it is stated by some that it was never intended that the formula should be used for anything other than small openings.

Talbot Formula. Another noted formula, derived by Professor A. N. Talbot, M. Am. Soc. C. E., from the Burki-Ziegler formula, is $A = C\sqrt[4]{D^3}$ in which the letters have the same significance as described above. The following is quoted from remarks by Professor Talbot relative to the value of the coefficient C: "I conclude that for rolling agricultural country, subject to floods at time of melting snow, and with the length of valley three or four times the width, one-third is the proper value for C. In districts not affected by accumulated snow and where the length of the valley is several times the width, one-fifth or one-sixth or even less may be used. For steep and rocky ground C varies from two-thirds to unity." This formula has been very generally adopted in the West and Southwest.

Formula for Run-Off. A formula which is based on the run-off and drainage area and gives the amount of water which must be taken care of may be written as follows: $Q = C R D$, in which Q is the amount of water in cubic feet per second, R is the rate of rainfall in inches, D is the drainage area in acres and C is a coefficient varying between 0 and 1, depending upon the soil, topographical conditions, etc. In a formula of this kind the rate of rainfall is sometimes taken as 1 inch or 2 inches per hour, 1 inch per hour on an acre being the equivalent of 1 cubic foot per second. This will not give correct results on small areas having

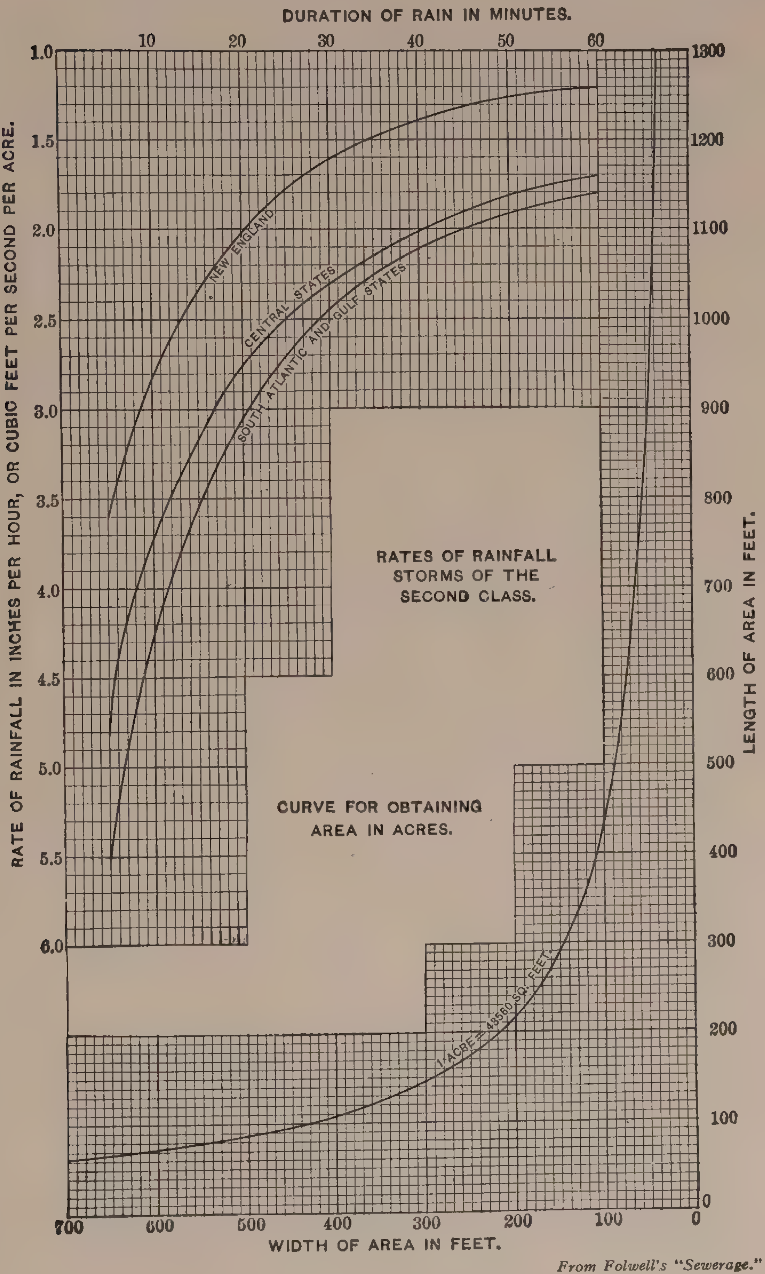


FIG. 224. Rainfall Curves.

a somewhat impervious surface and steep slopes, since there are periods in many storms where the rate for a few minutes may be as much as 4 inches. The curves shown in Fig. 224 may be used to determine the amount of rainfall for different lengths of time.

The application of the above formula is as follows: The drainage area is determined and an approximation is then made as to the length of time it will take a particle of water to flow from the farthest point of the area to the culvert or bridge opening. With this time as an argument, the rate of rainfall for this period of time is taken from the rainfall curves shown in Fig. 224. This rate of rainfall multiplied by the area will give the maximum amount of water in cubic feet per second that will fall upon the area, provided, of course, the assumption relative to rate of rainfall is correct. It may be found that in the case of some drainage areas the shape is such that if a part of the area is taken and a rate of rainfall corresponding, the amount of water to be carried away from this portion will be greater than when the whole area and a lower rate of rainfall is considered. As a basis for assumptions relative to the velocity of water flowing over the drainage area, the following table is given, which is computed by Kutter's formula for a stream 3 feet wide, 1½ feet deep, with side slopes of 45 degrees, using a value of $C = 40$, which is probably not too low for the rough and crooked channels of ordinary streams.

Slope of Channel	Velocity of Water in feet per second
1 in 20	7.06
1 in 30	5.75
1 in 50	4.46
1 in 75	3.64
1 in 100	3.15
1 in 150	2.57
1 in 250	1.99
1 in 500	1.41
1 in 750	1.15
1 in 1000	0.99

The quantity C, which is the percentage of run-off, involves another approximation, which depends entirely upon the judgment of the engineer. The value C can never be as great as one. In

fact, some of the most accurate observations which have been made in connection with the flow of storm water in sewers show that for water falling on an area that was compactly built up, the ground for a large part being covered with impervious pavements, the maximum for C was 80 percent. The values of C, which are generally assigned by Chamier to conditions which may be encountered, are as follows:

Flat country, sandy soil, or cultivated land	25 to 35 percent.
Meadows and gentle declivities, absorbent ground	35 to 45 "
Wooded hill slopes and compact or stony ground	45 to 55 "
Mountainous and rocky country or non-absorbent surfaces	55 to 65 "

About the only way, however, in which an accurate value of this coefficient can be obtained is to measure the flow at existing culverts or bridges during storms. The amount of rainfall should also be measured for each storm. Knowing the amount of rainfall, the drainage area and the measured flow, the quantity C can be determined by substituting the above known quantities in the formula. If such observations are carried out on an extensive scale some very valuable and dependable data may be obtained.

When the amount of water which comes to a point where the bridge or culvert is to be located has been ascertained, the size of opening can be determined by means of the formula $Q = F\,V$, where Q is the amount of water in cubic feet per second; F is the area of opening in square feet; V is the mean velocity of the water. The velocity, V, is determined from the formula $V = C\sqrt{R\,S}$ in which C is a coefficient; R is the hydraulic radius; S is the slope of the channel. It is seen that the flow of water then depends upon the shape of the waterway, its slope, and whether it is flowing full or partly full. The coefficient C may be determined by Kutter's formula, for which see any standard work on hydraulics, and it will here be found that C also depends upon R, S, and a value N, or a coefficient which represents the roughness of channel bed. To work out

TABLE No. 32

VELOCITY AND DISCHARGE IN VITRIFIED PIPE CULVERTS 12 TO 36 INCHES DIAMETER.

Velocity in Feet per Second; Discharge in Cubic Feet per Minute; Pipes Flowing Full.

(Formula $V = C \sqrt{R S}$; c calculated by Kutter's formula, with n = .013. Q = 60 a V.)

Grade of Pipe		12-inch		15-inch		18-inch		24-inch		30-inch		36-inch	
Per ct.	Inches per ft.	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q
10.0	1¼	13.73	647.0	16.24	1196.0	18.59	1971.5	22.91	4319	26.84	7905	30.46	12920
4.0	½	8.65	407.8	10.26	755.6	11.74	1244.0	14.47	2729	16.96	4995	19.26	8171
2.0	¼	6.13	289.0	7.25	534.2	8.30	880.4	10.23	1930	11.99	3532	13.62	5777
1.0	⅛	4.33	204.3	5.13	377.8	5.87	622.6	7.24	1396	8.48	2497	9.63	4085
0.8	$\frac{3}{32}$	3.87	182.6	4.59	337.7	5.25	556.8	6.47	1220	7.58	2233	8.61	3653

the requisite size of opening in each instance would be a long and tiresome task. It is possible, however, to construct curves or compute tables which will greatly facilitate the work so that but little time is lost. Table No. 32 is based on Kutter's formula and shows the discharges of different sizes of circular pipes flowing full for various slopes.

Observation of High Water Marks. High water marks are of the greatest assistance in determining the size of opening required, particularly if they are measured at a point where the stream is narrow and one is reasonably sure that the bed conditions are the same as at the time of the occurrence of the high water. It should be remembered, however, in seeking evidences of high water that the investigation should be made covering a long period of years. It has been found in studying the flow of streams that a continuous record of five years will not include all of the varying conditions of stage to which that stream is subjected. The absolute extremes of high and low water sometimes occur a few years and sometimes many years apart. The value of old data therefore in connection with high water marks will be appreciated. The measurement of the waterways of existing bridges along the same stream will be an excellent guide if they have been built for some time. Due allowances should be made for the obstruction of the channel by piers, as the waterway is greatly reduced in some cases where it is proposed to erect a series of short spans resting on piers across a wide channel.

Measurement of Flow. The amount of water may be determined from stream measurements. What has been said above in regard to long term records applies in this case as well, for a record of stream discharge measurements for a year is practically worthless, when considered by itself, in so far as determining the size of required opening. The government, however, for several years past has been devoting considerable attention to this subject, so that records of several years' duration are now available on many of the more important rivers in the United States. It is possible to approximate the run-off from a drainage area, even though the stream has not been measured, by comparing it with one of similar characteristics, where the

run-off has been determined. In such a case the same percentage of run-off would be applied to the amount of water falling on the area in question.

Economy of Design. The economy of designing a bridge or culvert to take the maximum discharge of water from an area should be determined. There may be instances where the water may be allowed to pond up back of the highway, the opening discharging under a head, with no great damage resulting provided the banks are protected. It would be economical to build the structure to meet maximum conditions if the interest on the additional first cost was less than the cost to repair whatever damage was incurred by the use of a structure furnishing a smaller waterway. Where a loss of life would be involved, however, the structure should be designed to meet maximum conditions.

Construction of Bridges and Culverts

It is not the purpose of this chapter to consider the design of either bridges or culverts in so far as determination of stresses or the strength of parts to resist stress is concerned, since the subject of design is thoroughly covered by standard treatises. The remainder of the chapter will, therefore, be devoted to a brief consideration of some of the more general points relative to construction and cost, culverts and bridges being treated separately.

Types of Culverts. Culverts are commonly classified as pipe, box, and arch. In the construction of culverts a variety of materials are employed. Pipe culverts are constructed of vitrified clay, cast iron, corrugated metal, concrete, brick, and timber; box culverts are built of stone, concrete, and wood; arch culverts are constructed of stone, concrete, reinforced concrete, and brick. The selection of the type of culvert and the material to be used is largely a question of economy, particularly in the case of small waterways. The availability of materials, their first cost, freight charges, cost of hauling, and cost of construction all have to be considered. There may be cases where considerations other than cost would determine the

selection of the type, such as, for example, the depth of fill over the culvert. An opening having a circular cross-section will discharge more water when flowing full than an opening of any other shape and of the same area. Some kinds of pipe are, however, not manufactured in diameters of over 3 feet, and pipes of any material are rarely found which are over 5 feet in diameter. When larger areas of waterway are required, therefore, it will be necessary to use either a culvert of the box or arch type or two or more lines of pipe, the selection being based on the relative economy of each method.

Design. Culverts are required to support the weight of the material which covers them and also the weight of any superimposed loads. They may also be subjected to severe expansive forces caused by water freezing within. The latter condition, however, is a very rare occurrence in well designed culverts. The amount of load carried to the culvert is indeterminate on account of the unknown action of earth pressure and the distribution of superimposed loads through the same. The load reaching the culvert will, therefore, have to be assumed. In using standard pipes of cast iron, corrugated metal, or vitrified clay, it is ordinarily not necessary to investigate their strength as far as load-carrying ability is concerned, since they have been used under sufficiently varying conditions to prove that they will resist successfully any load that they are likely to receive, provided the pipes are properly placed. The design of reinforced concrete and concrete pipes, box and arch culverts should be carefully prepared so that they will support the loads which they must carry. In order to save work necessitated by the design for the many varying conditions which are encountered, it is customary to prepare standard plans of these types of culverts which are designed to meet average conditions and may be used in practically all cases. Although such designs may contain some excess of material, the increased cost is not great and is more than overbalanced by the saving in office work.

Location. The proper location for a culvert can only be determined by an examination of conditions in the field. It is true that some idea as to the need of a culvert may be gained

from looking over the profile of the road on the drawing, since culverts are usually needed at all low points of the grade. When these places are examined in the field, however, it may be found that the ground slopes away from the road on both sides and hence, in some cases, no culvert will be needed to carry the water across the road. Other places which are not apparent on the plans may be found by a field examination where water will pond and cause property damages unless a culvert is constructed to remove it. It may be possible to use existing culverts if they are in good condition and have the required size of waterway. Where the grade or location is changed very materially it may be economical to use the old culvert and extend it out to meet the new lines of the work. When a new culvert is required, sufficient information should be obtained, as outlined in Chapter III, so that in designing a culvert all data relative to the depths at the inlet and outlet end and depth of cover will be at hand. In cuts with shallow side ditches, in localities where the highways are curbed, and in any place where it is not possible to obtain sufficient cover over the culvert and still have the inlet end of the culvert above the surface of the ground, some form of catch basin or drop inlet, which were described in Chapter VI, will have to be built around this end of the culvert. Small culverts of the pipe or box type and small arch culverts are usually constructed at right angles to the axis of the road. When the culvert is used on hills to carry the water from one side of the road to the other, if the culvert is placed at an angle across the road it affords a somewhat easier access to the water. This same scheme is also used in some cases to obtain sufficient cover over the culvert, or to bring the point of outlet at a more convenient place.

Construction. Culverts of all types should be laid on a good foundation. It is very important to examine the material of which the foundation is composed, since excessive settlement causes stresses in the structure that it is not designed to take. The culvert should be laid true to line and grade.

Pipe culverts should be firmly bedded on the foundation, and where the pipes are of the bell and spigot type places should be

cut out in the foundation to receive the projection. If the soil furnishes a very poor support the pipes should be bedded in a layer of concrete or broken stone. Backfilling for pipe culverts should be composed of a selected fine material, free from large stones. Care should be taken to place the filling around and under the pipe, tamping the material in thin layers. Puddling

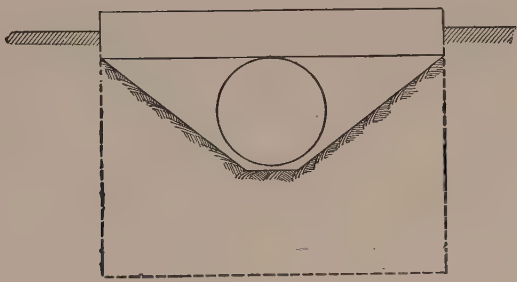


FIG. 225. Headwall for Pipe Culvert.

may be necessary in some cases. A headwall should generally be constructed on both ends of a pipe culvert. The use of headwalls makes it possible to use a somewhat shorter culvert than would otherwise be necessary. Headwalls for small culverts are usually built parallel to the center line of the road, as shown in Fig. 225. Sometimes, however, it may be found advisable or more economical in the case of culverts of large size to construct wing walls, either straight or flared, as shown in Fig. 226.

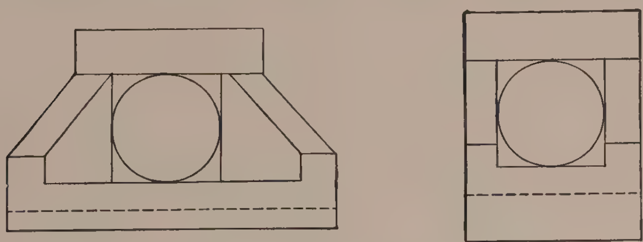


FIG. 226. Headwall with Wing Walls.

Concrete and stone masonry are used in building headwalls. Cheapness, durability, and the fact that concrete can be moulded into any form desired render it a very satisfactory material

for this purpose. The bottom of the headwall should be carried 18 inches or more below the bottom of the pipe to prevent washing it out.

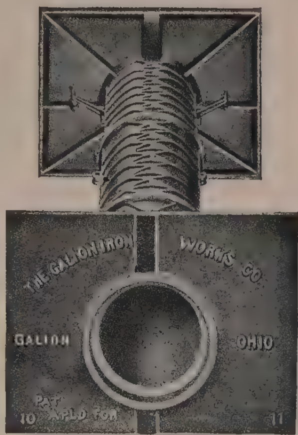
When box or arch culverts are to be constructed and a poor soil is encountered, it is possible to spread the footings so as to lessen the pressure on the foundation or to carry them down deeper to a firmer bearing. If there is liable to be any danger from the standpoint of scour, the bottom of the culvert should be paved. If this danger is not present the stream bed may be made to serve as the invert. Headwalls should be constructed for box and arch culverts in the same manner as described for pipe culverts.

Vitrified Pipes. Vitrified pipes used for culverts should be the best quality salt glazed sewer pipe of the double strength type, with socket joints. This pipe is made in 2-foot lengths with diameters from 12 to 36 inches. The pipes are laid in the trench with the socket end towards the inlet, so as to have at least 15 inches of material over the top of the pipe at its highest point. The joints are sometimes filled with cement. Under conditions ordinarily encountered in highway work vitrified pipe makes a very satisfactory as well as a cheap culvert. During 1911 the approximate costs per foot in less than car load lots were: 12 inches, 35 cents; 15 inches, 47 cents; 18 inches, 66 cents; 20 inches, 79 cents; 22 inches, $1.05; 24 inches, $1.15; 27 inches, $1.58; 30 inches, $1.93; 36 inches, $2.45. The cost per linear foot of vitrified pipe culverts in place, as given by the Massachusetts Highway Commission, is approximately as follows: 12 inches, 75 cents; 18 inches, $1.50; 24 inches, $2.50; 30 inches, $3.75. The average cost of laying different size pipe culverts in Maryland in 1908 and 1909, work being done by the State Highway Commission, was approximately as follows, cost of pipe included:

12 inches	15 inches	18 inches	20 inches	24 inches	30 inches
$0.70	$1.10	$1.40	$1.30	$2.00	$2.90

Cast Iron Pipes. Cast iron water pipe with bell and spigot joints has been used in culvert construction for a long time.

Standard cast iron water pipe is manufactured in 12-foot lengths and hence is not so easily adaptable for use. Until within a few years the standard water pipe was the only type of cast iron pipe available. At the present time special culvert pipe can be obtained which is made in 4-foot lengths. The weight of the sections is still further reduced by making use of a thinner cast iron shell reinforced with projecting ribs of the same material. A special type, similar in cross-section to a spherical triangle, has also been developed in which the three sides are shipped as separate pieces in 3- to 4-foot lengths and are fitted together in the culvert trench. Cast iron is very strong and will last for many years. This kind of pipe can be placed within 6 inches of the road surface without danger of breaking. The principal objection to standard cast iron water pipe, outside of its cost, is its weight, which makes it expensive to handle. The cost will vary between 1.5 cents to 2 cents per pound. The weight per foot of one grade of pipe for some of the sizes from 12 inches to 72 inches in diameter is as follows: 12 inches, 85 pounds; 18 inches, 200 pounds; 24 inches, 300 pounds; 36 inches, 500 pounds; 48 inches, 850 pounds; 60 inches, 1,250 pounds; 72 inches, 1,750 pounds. The cost per linear foot of cast iron pipe culverts in place, as given by the Massachusetts Highway Commission, is approximately as follows: 12 inches, \$2.25; 18 inches, \$3.50. The average cost of laying different size cast iron pipe culverts in Maryland in 1908 and 1909, work being done by the State Highway Commission, was approximately as follows, including cost of pipe:



Courtesy of the Galion Iron Works.

FIG. 227. Special Form of Cast Iron Culvert Pipe.

12 inches	14 inches	16 inches
\$2.50	\$2.90	\$4.50

Corrugated Metal Pipes. Corrugated metal pipe, see Fig. 228, is made in any length desired ranging by multiples of 2 feet up to 36 feet or is made in nest sections which are later bolted together in the field. The pipe may be laid to within 6 inches of the road surface. Since it weighs about one-twentieth as much as cast iron it is much more easily transported. The nest sections are of a particular advantage in this respect. Care should be taken to select pipes made of the proper kind of metal. Wrought iron is superior to steel as far as its non-

Courtesy of the Galion Iron Works.

FIG. 228. Corrugated Metal Pipe.

corrosive properties are concerned, and hence pipes made of iron generally have a longer life. The non-uniformity of results obtained with metal culverts of different makes has been due almost entirely to the different kinds of material used in the manufacture. The approximate cost per linear foot of a few sizes of one type is as follows: 8 inches, 54 cents; 12 inches, 72 cents ; 18 inches, $1.04; 24 inches, $1.44; 36 inches, $2.84; 48 inches, $4.14; 60 inches, $5.18; 72 inches, $6.29. The cost of laying corrugated metal pipe culverts would probably not be much different than that of vitrified pipe although in some cases it would be less.

Concrete Pipes. Concrete pipes may be cast and laid as any other form of pipe. When laid in situ, the pipe is constructed as a monolith. By this last method, the base is generally carried out for a width equal to the diameter of the pipe, and in effect the culvert becomes really nothing more than a small arch culvert with a circular opening. This is not the most economical method for constructing pipes of concrete. When cast previous to laying, the pipes are made in lengths of from 4 to 8 feet with

thicknesses varying from 2 to 6 inches depending upon the diameter. The joints are made tapering, with some form of socket or are simply square faced. The last type has worked out very satisfactorily in practice. Concrete pipes weigh more than cast iron pipes, but may be constructed to cost about one-fourth as much. The following table, which was made by O. P. Chamberlain, shows the relative thickness, weights, and cost of cast iron pipe and pipes of plain concrete with square faced ends:

Size and Kind of Pipe	Thickness in Inches	Weight Lbs. per Lin. Ft.	Cost per Lin. Ft.
12 in. diam. cast iron......	$.\frac{33}{64}$	75	$1.22
12 " " concrete......	2	88	0.16
18 " " cast iron......	$.\frac{47}{64}$	167	2.72
18 " " concrete......	3	220	0.36
24 " " cast iron......	1	250	4.07
24 " " concrete......	4¼	420	0.68
30 " " cast iron......	$1\frac{1}{16}$	334	5.43
30 " " concrete......	4½	602	0.88
36 " " cast iron......	1⅛	450	7.32
36 " " concrete......	4¾	676	1.10
42 " " cast iron......	1⅜	600	9.75
42 " " concrete......	5¾	960	1.55
48 " " cast iron......	$1\frac{7}{16}$	725	11.78
48 " " concrete......	6	1131	1.83

Stone Box. Stone box culverts are made up of two side walls which are bridged over by cap stones. If the stream running through the culvert has enough force to scour out the bed, the bed should be paved with cobblestones or other suitable material. The side walls should be carried to a good depth below the bottom of the stream bed, 18 to 30 inches generally being sufficient. The side walls are usually constructed of dry rubble masonry, and of varying thicknesses depending upon the height of opening. It is good practice not to make the thickness of the wall at the top less than 2 feet in the smallest size culverts. While the faces of the walls are generally straight, the backs of the walls are sometimes built with a batter. The wings of the culvert are formed by extending the side walls out straight and stepping them down. When the capstone is made of stone slabs, the

specifications usually require that its thickness shall be at least 12 inches for all sizes up to 4 feet. Such stones, however, are sometimes difficult to obtain and are expensive to handle, particularly for large culverts. Reinforced concrete slabs are used in place of the capstones for a cover in some cases, and it is possible with this kind of construction to build much longer spans with a thinner cover than it would be where capstones might be used. Fig. 229 shows a 3 by 3 stone box culvert as

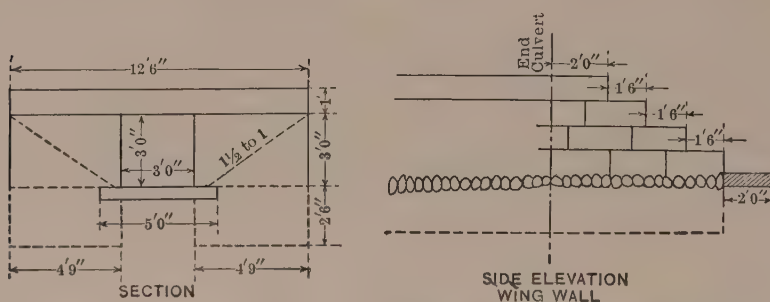


FIG. 229. Stone Box Culvert. Massachusetts Highway Commission.

constructed by the Massachusetts Highway Commission. In New York State culverts have been constructed in which the rubble masonry walls are spanned by steel I-beams, spaced a distance apart depending upon the width of opening, on top of which rest reinforced concrete slabs, which are always made 6 inches thick. The length of span for which this type of construction is adaptable is only limited by the span for which it is no longer practical to use I-beams.

The following cost data is given by Gillette for constructing a 3 by 3 dry masonry culvert 36 feet long. The culvert contained 50 cubic yards of stone which was taken from a rock dump. The labor cost was as follows:

20 cubic yards excavation at 22 cents	$4.40
Masons, 60 hours at 40 cents	24.00
Laborers, 130 hours at 20 cents	26.00
Team, 40 hours at 45 cents	18.00
Derrick, 40 hours at 15 cents	6.00
Total	$78.40

The average price for rough rubble masonry is about $5 to $6 per cubic yard.

Reinforced Concrete Box. Reinforced concrete box culverts are built in a manner similar to stone box culverts, except that concrete is used throughout in their construction. The side walls are made quite thin in comparison with those of stone box culverts, ranging from 4 to 8 inches in thickness depending upon the height. In the larger size culverts the side walls are reinforced. Where there is no danger of scour in the stream bed, the walls are carried 2 feet below the stream bed, and a footing is constructed under each wall which is from 9 to 12 inches in thickness and of a width sufficient to properly support the wall.

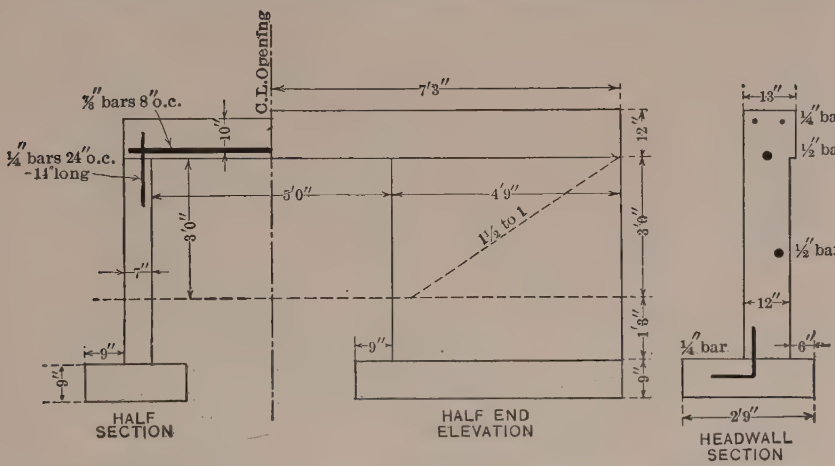


FIG. 230. Reinforced Concrete Culvert. Massachusetts Highway Commission.

In places where scour may occur, a concrete bottom is built in the culvert throughout its entire length. In this case the side walls are not carried any deeper than the bottom of the paving. A cut-off wall, generally a part of the head wall, is built at either end, extending about 2 feet below the bottom of the culvert. Fig. 230 shows a typical standard design of a reinforced concrete culvert of the Massachusetts Highway Commission. The cost of concrete culverts will vary on the average from about $7 to $12 per cubic yard.

Timber Box. Where other materials are available there is no excuse for building a timber box culvert of the kind that is frequently encountered, which consists of two plank sides supporting a plank top. Such construction is not economical, as the planks soon rot out and the culvert becomes a source of danger to the passing traffic. Frequently small span culverts are built with very crude stone side walls which support wooden beams carrying a plank floor. It is difficult to maintain the road surface adjoining the plank floor, and frequently the floor is

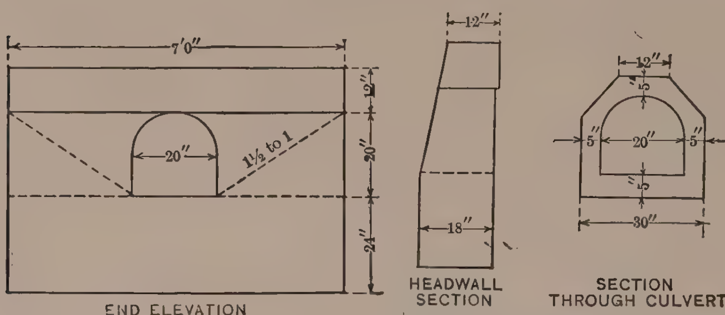


FIG. 231. Concrete Arch Culvert. Massachusetts Highway Commission.

allowed to get into such a delapidated condition of repair that it becomes unsafe. There may be occasions, however, where the timber box is an economical type of culvert to construct, but if so it should be built on substantial lines. In the Province of Saskatchewan, Canada, timber is very plentiful and box culverts of this material are constructed there to some extent which give very good satisfaction. Heavy timbers are used and the construction in every way is made in a substantial and workmanlike manner.

Arch Type. A typical small arch culvert, as constructed by the Massachusetts Highway Commission, is shown in Fig. 231. It will be noticed that no reinforcement is used in this design and that straight head walls are placed parallel to the center line of the road. Fig. 232 shows a standard culvert of plain concrete as built by the Missouri Pacific Railroad. Many of the small arch culverts built are constructed with an invert of concrete

paving. The economy of omitting the paving and carrying the side walls down below the stream bed can be ascertained by estimating the relative amount of concrete used in the two methods of construction. Reinforced concrete arch culverts

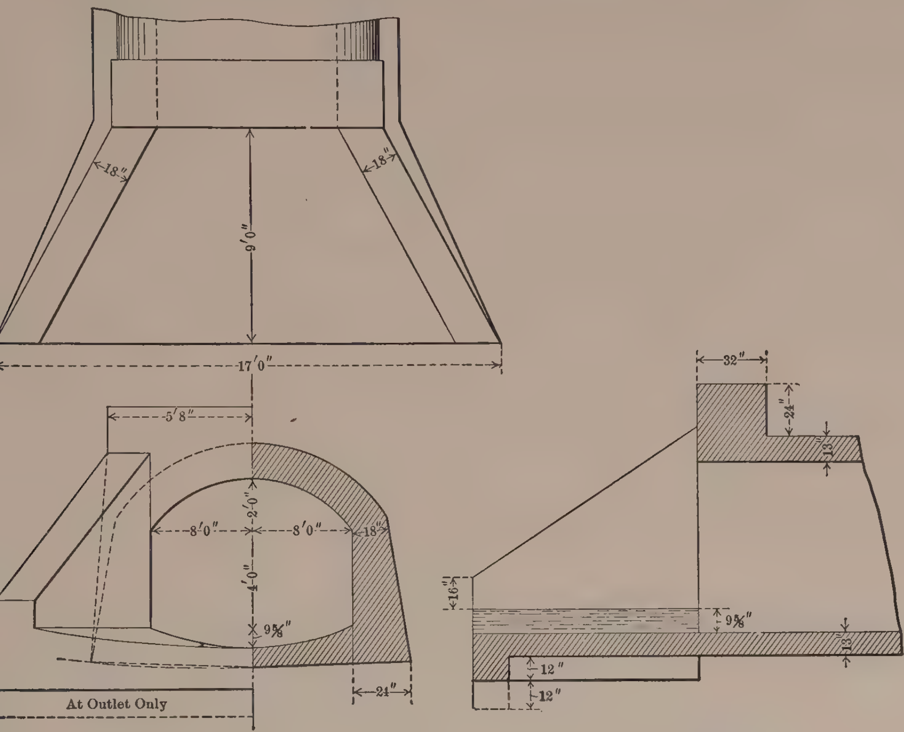


FIG. 232. Concrete Arch Culvert. Missouri Pacific Railroad.

are built in a similar manner to those of plain concrete. The advisability of reducing the section of the arch ring from that which is required for plain concrete is questionable for small culverts. The saving in the amount of concrete would be very small. If any reinforcement is to be used in the arch ring, provide the requisite amount without reducing the concrete section. The cost of concrete for this class of work will vary from $8 to $12 per yard, governed considerably by the cost of the form work. For small arch culverts a steel form has been placed upon the market which is capable of being rapidly erected

and easily removed. A steel form of this type would greatly decrease the expense of forms where a considerable yardage of the same size of culverts is to be constructed.

Types of Bridges. There are many types of bridges which may be classified as follows:

Joist and plank floor Wood trusses Wood viaducts	Timber bridges
I-beams Plate girders, both through and deck Pony trusses Trusses, through and deck Viaducts Cantilevers Suspension types Arch ribs Draw bridges	Steel bridges
Beam Girders Arches	Concrete and Reinforced Concrete
Arches	Stone

The selection of the type of bridge best suited for any crossing is governed by the cost of structure, its appearance and adaptability. Conditions at some crossings, such as headroom, requisite waterway, character of foundations, elimination of piers, or the maintenance of a navigable channel absolutely preclude the use of certain types which otherwise might be desirable. Generally too much importance is attached to the first cost. In the case of a small and unimportant structure it is the first cost that looks large, and many communities are so situated that they would prefer to spend money for an improvement and obtain the use of it rather than to wait and raise the money required for a structure more permanent and stable in character. The expenses of a new bridge in some places would amount to a large sum, and generally when any appropriation is made it is so small that the engineer may be obliged to build a structure which he knows in the end will be the most expensive. When

the amount of money to be expended is not in question or is liberal, the cost of different types of bridges can be figured on a capitalized cost basis and a comparison made, thus obtaining the cheapest type of structure. Low annual cost, although greatly to be desired, is not the determining factor in some cases where appearance is of great moment. Very little attention is given in this country to æsthetics in bridge design, particularly in steel bridges of the small types. The use of reinforced concrete structures of both the arch and girder type, however, has made it possible to erect structures which harmonize with the surroundings better than those of steel. Many of the steel bridges in country towns are sold to the town representatives without the services of an engineer. The decision as to the type of structure, whether it is a girder, pony truss or through truss, rests largely with the contracting bridge company, since the townspeople are dependent upon its advice. It is not surprising, therefore, that many of our existing steel bridges neither look well nor wear well. For short spans there are a number of types that may be used, and it is principally a question of economy as to which type should be adopted. In the case of long spans some of the types cannot be used at all or else it is a case of comparing a series of short spans against one long span or a series of longer spans. The area of opening, foundations, and topography then will impose certain conditions that must be met, and the problem of selection will finally be confined to a few types where it is a question of cost versus permanence and appearance.

Design. Bridges are subjected to the same loads as culverts, except in the case of steel bridges with some form of plank or paved floor, where the weight of the earth fill is not present. The distribution of the live load in this instance will be somewhat different than where its effect is transmitted through several feet of earth. The assumptions as to its distribution will have to be based on the engineer's judgment along lines of safe and practical design. Impact stresses are usually negligible. All bridges should be designed to carry at least a 15-ton road roller or its equivalent. Care must be taken to obtain a firm founda-

tion for all substructures and to make provisions against all possibility of scour. The abutments and piers may be built of stone masonry or concrete, the latter material being used to a large extent for this purpose. Æsthetic considerations should not be lost sight of and the character of the structure should be such as will well fit its surroundings.

Location. The problem of location for a bridge requires more study than in the case of a culvert. The location will also affect the type of structure to some extent. In some cases it may be found that to secure the required area of waterway will necessitate raising the grade on the approaches. If the alignment of the highway on either side of the stream is not good it may be advisable to shift the location of the bridge up or down stream from the original location with a consequent improvement of the alignment. There may be occasions where lack of good foundations at a reasonable cost would warrant placing the bridge at a point where good foundations will be readily accessible, the saving in cost on the bridge being more than enough to pay for the relocation of the approaches. The faces of the abutments or piers should always be in a plane parallel to the current of water. Unless the crossing is at right angles to the direction of the current it will be necessary to build the bridge on a skew, which is always somewhat more expensive, and a bad skew is very undesirable, especially in an arch, due to the complexity of the strains resulting.

Bridge Floors. The floor systems on which the wearing surfaces rest are of two principal types, solid floor systems, generally composed of concrete, and the open framework system, formed by intersecting stringers and floorbeams. The first type is common to all concrete structures. It is possible, when this type is used, to build on it any type of wearing surface that may be desired, provided the structure is designed to take the load. There are no special features in connection with the construction of pavements on solid floors of concrete bridges except in the case of long span bridges, when some further provision for expansion and contraction must be provided for than is required in pavements on streets. Both types of floor systems are used on steel

bridges. The solid floors are made up of concrete or arches sprung between longitudinal or transverse steel beams, of concrete on buckleplates supported on a steel framework, of concrete on a floor of riveted steel shapes, of reinforced concrete slabs supported on a steel framework, or of reinforced concrete slabs and beams in cases where the steel framework is omitted entirely. The same remarks apply relative to the construction of the wearing surface on these types of solid floors as were stated above for concrete structures. When some one of the above kinds of solid floors is not used in connection with steel bridges, the framework composed of the steel floorbeams and stringers is covered with a plank floor, which may act as the wearing surface itself or may support a wearing surface of some other kind of material. With the exception of bascule bridges the type or form of steel structure has no bearing on the type of floor system or wearing surface to be used. There are cases where the increased cost of superstructure entailed would prevent the solid floor from being used due to the increase in dead load.

Wearing Surface. It has been stated that the wearing surface on a solid floor of either a concrete or steel structure may consist of earth, gravel or broken stone, or cement-concrete, bituminous, brick, stone or wood block pavements. When the steel framework of the floor system is covered with planks, they may serve as the wearing surface or may support a wearing surface of any one of the following types: another layer of planks, a wood block pavement or a brick pavement. The planks should be treated with some preservative material whether they act as the wearing surface or as the support to another pavement. When a two-layer plank floor is built the planks in one layer are placed at right angles to the center line of bridge and the planks in the other layer are laid on lines at 45 degrees with the center line or vice versa. In some cases a thin bituminous surface similar to that used on any type of road or pavement is applied to a plank floor. Brick and wood block pavements are frequently laid on the plank floor support without any intervening cushion layer.

To discuss the construction, wear, and cost of the different types of wearing surface is beyond the scope of this chapter, since

there are such a variety of methods used and the traffic and other conditions affecting the life are decidedly variable. A brief statement, however, will be made relative to the wear of plank floors since this type is so commonly used. Under ordinary conditions the life of a plank floor is stated to be from two to eight years. There may be cases where it is necessary to remove the planks within this limit of time on account of decay rather than of wear caused by traffic. On Brooklyn Bridge the 2½-inch wearing surface has to be replaced every four months because the traffic is so dense. Detailed information relative to the construction and wear of different types of bridge floors may be found in the reports on "Types of Surfacing to be Adopted on Bridges, Viaducts, etc.," presented at the Third International Road Congress held in London in 1913.

Steel Bridges. The life of a steel bridge, if properly constructed and maintained, is generally stated to be from forty to fifty years. The character and amount of the traffic usually changes materially during this time, hence a new structure may be required, although the bridge has not deteriorated to an extent which would require renewal. Many small bridges which are built by contract on the lump sum basis are so skimped in material as to considerably shorten their life. The floor system of steel highway bridges generally deteriorates much more rapidly than the main members, due to the fact that there are many more places for the dirt to lodge. Water wets the dirt and soon rust begins to form, which rapidly eats away the steel. A steel bridge should be painted at least once every three or four years and perhaps more often, depending upon climatic and other conditions. Steel near salt water, where the spray can reach it, will rust rapidly and requires frequent painting. The floor systems of bridges over railroad tracks which are exposed to the gases from the smoke stacks of the engines will require painting with special kinds of paint in order to best protect the metal. Bridge painting is unfortunately entirely neglected in many small towns, with the consequent rapid deterioration of the bridges.

I-Beam Bridges. I-beams with the ends resting on a beam

supported by vertical beams or with the ends resting on abutments of either stone or concrete masonry are commonly used for short spans. The former is called a leg bridge and cannot be recommended. The maximum economical span is about 32 feet.

Pony Truss and Plate Girder Bridges. When the span is such that I-beams are no longer economical either a riveted pony truss or a plate girder may be used. Low truss bridges are economical up to spans of about 80 feet, while the limiting span of plate girder bridges is about 100 feet. It is doubtful, however, whether either of these types would be economical when compared with a concrete structure. The construction of pony truss bridges, with light sections, cannot be recommended. If such a structure is to be used, it should be built with an excess of metal over and above what is required so as to provide requisite stiffness and rigidity to the structure. Pin connected pony trusses should never be built.

Pin Connected and Riveted Trusses. Both pin connected and riveted trusses with parallel chords are used for spans from 80 to 170 feet in length. For spans from 160 to 220 feet a Pratt truss with inclined upper chords is usually employed, and for spans over 220 feet a truss of the Petit type is adopted.

Cost. The cost of the steel work in a bridge depends upon the material, fabrication, transportation, and erection. The cost of these items is naturally extremely variable, depending upon the type of structure, the distance of site from the railroad, and conditions which determine the methods of erection to be used. An average cost for steel in place may be taken as 4 to 5 cents per pound.

Timber Bridges. Timber highway bridges are not generally constructed at the present time except as a temporary expedient. Considered from any other standpoint the construction of timber bridges is uneconomical and decidedly unwise, due to their rapid deterioration and the liability of their being destroyed by fire.

Concrete and Reinforced Concrete Bridges. Concrete in itself is practically indestructible and has an indefinite life. Within the past ten years the increase in the use of this material

for structures of all conceivable kinds has been very rapid. The knowledge gained in the past ten years of the action of steel and concrete in combination has placed this type of construction on the same plane with structural steel when considered from the standpoint of theoretical design. The use of reinforced concrete has also made it possible to construct bridges for many spans for which plain concrete bridges could not be economically built. If the structure lies under a heavy fill, any material increase in the live load will not increase the stress in the structure to any great extent, since the dead load is so large in proportion to the live load. The materials of which reinforced concrete are made are generally available. In fact, the stone and sand which make up the greater part of the bulk can frequently be obtained within easy hauling distance. The only materials in many localities that may have to be brought from any great distance are cement, lumber, and steel reinforcement. The materials are cheap and to incorporate them together and build forms to hold the mixture is not very expensive, if the work is properly managed and the structure is not too complicated in its details. Moreover, the ease with which concrete can be moulded into different shapes makes it possible to add greatly to the appearance of the structure without increasing the cost to any extent. A very pleasing finish can be given the concrete at a slightly increased expense, which greatly improves the appearance of the structure. One method which has been used is to finish off the exposed face of the concrete with mortar composed of cement and either sand, stone chips or pebbles as the aggregate. This small aggregate may be screened out so that a uniform size will be used. This mortar face is placed at the same time as the concrete in the main part of the structure so as to insure a good bond and is made from 1 to 1½ inches thick. When the concrete is still green the forms are removed and the concrete is scrubbed with a stiff brush, which removes the finer particles of the mortar face and exposes the aggregate. A few days later the surface is washed with a solution composed of one part of muriatic acid and two parts of water. This solution, which is applied with a white-wash brush, is allowed to remain on for about thirty minutes, during which

time it is scrubbed with a stiff brush. The surface is then thoroughly washed with a hose.

In an article by E. P. Goodrich,* M. Am. Soc. C. E., numerous examples are cited where reinforced bridges have been constructed at a lower first cost than steel bridges for the same location. He draws the following conclusions as to the relative costs of maintenance of the two types of structures:

"Steel highway structure: depreciation and sinking fund for replacement, at least 5 percent; cost of maintenance of timber floor, 4 percent; cost of painting, less than 2 percent. Total cost in excess of interest charge on first cost varies from 7 to 11 percent.

"Concrete structure: depreciation and sinking fund not to exceed 2 percent; cost of maintenance of regular pavement on earth road surface on concrete structure, less than 1 percent. Total annual cost in excess of interest charge on first cost not to exceed 3 percent."

Girder Bridges. Among the simplest types of reinforced concrete bridges are the deck girder and through girder. The

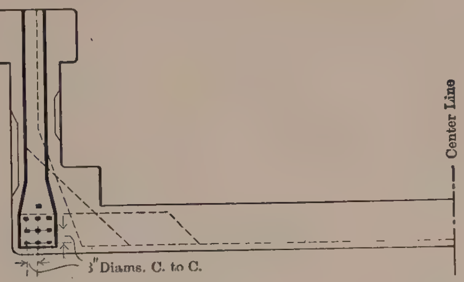


FIG. 233. Reinforced Concrete Girder Bridges. Illinois Highway Commission.

former for short spans might more truly be called a beam and slab bridge, as the longitudinal members would hardly be deep enough to warrant calling them girders. As the span increases in length the girders increase in depth.

The Illinois State Highway Commission has developed a

* See *Engineering and Contracting*, March 17, 1909.

TABLE No. 33

COST OF REINFORCED CONCRETE GIRDER BRIDGES.
ILLINOIS STATE HIGHWAY COMMISSION.

Dimensions:										
Clear span in feet	7	12	14	20	25	30	35	40	50	60
Width of roadway in feet	18	16	16	16	14	16	16	16	16	16
Height of abutments in feet	7	9.5	9	13	13	11	15	16	15	16
Quantities:										
Concrete in substructure, cubic yards	22.71	35.60	23.74	56.79	44.62	51.62	71.40	64.23	73.75	109.00
Concrete in superstructure, cubic yards	6.91	11.85	14.93	25.12	24.20	41.61	52.40	62.35	65.00	97.07
Steel in superstructure, pounds	670	1,223	1,647	3,910	5,085	6,786	8,956	10,925	14,172	20,333
Steel in substructure, pounds	850	1,290	700	1,428	1,799	1,849	2,756	2,271	2,328	3,620
Cost:	Per Cu. Yd.	Per Cu. Yd.	Per Cu. Yd.	Per Cu. Yd.	Per Cu. Yd.	Per Cu. Yd.	Per Cu. Yd.	Per Cu. Yd.	Per Cu. Yd.	Per Cu. Yd.
Cement	$1.35	$1.85	$1.56	$1.87	$1.87	$1.43	$1.90	$1.70	$2.35	$1.31
Stone[a] or gravel[b]	[a]2.44	[b]1.19	1.64	[a]0.88	[a]2.97	[a]1.83	[b]0.72 [a]1.45	[b]2.43	[b]1.60	[a]1.50
Sand	0.61	.....	0.72	1.40	1.47	1.24	0.14	0.70	.....	1.11
Forms	1.50	2.16	1.44	1.74	2.57	1.84	1.34	2.15	3.24	1.62
Steel in place	1.16	1.53	1.44	1.37	1.90	2.43	2.23	2.01	2.32	2.43
Mixing and placing concrete	1.61	1.23	2.05	1.27	1.14	1.70	1.02	1.55	1.53	1.14
Excavation	1.28	1.09	1.00	1.45	1.13	1.85	0.73	2.56	2.02	2.33
Total	$9.95	$9.05	$9.85	$9.86	$13.05	$12.38	$9.33	$13.10	$13.08	$11.43

reinforced concrete girder bridge of the through type which has been used to a considerable extent throughout that State for spans up to 60 feet in length. Fig. 233 shows a cross-section of this bridge and the general scheme of reinforcement. Table No. 33* gives the cost of constructing some of these bridges of different spans.

Arch Bridges. Arch rings are built with the intrados line conforming to either a semi-circular, segmental, parabolic, elliptical or some multiple centered curve. The semi-circular arch has been used to a great extent, but since the common use of reinforced concrete, arches with flat curves have frequently been constructed. The flatter the arch the greater the thrust on the abutment, hence care should be taken to see that the foundation provided under the abutment is capable of withstanding this pressure. The ratio of the span to rise will usually be determined by physical conditions such as the waterway required, head-room, grade of road bed, location of piers, cost of foundations, and appearances. The cost of concrete arch masonry will vary from $8 to $15 per cubic yard in place.

Guard Rails

Guard rails should be placed at the tops of all embankments and at culvert ends where there is the slightest element of danger. Wood, iron, and concrete are the materials used in the construction of guard rails. Guard rails on fills are placed 12 inches from the edges of the embankment toward the center of the road; on concrete or masonry headwalls they are placed generally in the center of the masonry.

On concrete bridges of the deck type, side rails may be made of pipe railing or some form of concrete fencing. Bridges of the through girder type whether of steel or concrete do not need any railing unless the span is so short that the depth of the girders is not high enough to afford sufficient protection. The fencing on steel truss bridges is made of pipe or railing composed of steel shapes riveted together.

* See *Engineering and Contracting*, Feb. 2, 1910.

Wood Rails. Wooden guard rails are usually built so that the top rail is 3 feet 6 inches above the ground. The posts are 6 inches in diameter and 7 feet long. They are spaced 8 feet center to center. The top rail is 4 inches square, set cornerwise in V-shaped notches sawed in the tops of the posts. The tops of the posts are sometimes sawed off slanting towards the center of the road and the top rail is then 2 inches by 6 inches, laid flat, The top of the lower rail is placed about 1 foot 3 inches below the bottom of the top rail. The lower rail is generally a 2 by 6 inch board, nailed to the road sides of the posts, which have been previously notched to receive it. The posts are of chestnut or of cedar with the bark shaved off. The rails are planed timber, usually pine or spruce. All joints and exposed surfaces are well painted with a light-colored paint, white lead often being specified for this purpose. The first cost of wooden guard rails in place is ordinarily between 20 cents and 30 cents per linear foot and the cost of maintenance is from 5 to 6 cents per linear foot per year.

Iron rods are used sometimes in place of wooden posts where a guard rail is needed for a culvert headwall or for a ledge. The top of the rod is forked to receive the 4-inch square wooden rail. The lower rail is frequently omitted.

Pipe Rails. Gas pipe railing is also used on headwalls of culverts, or on ledge. The pipe used is 1½ or 2 inches in diameter. The railing is 3 feet 6 inches high and is built with two or three lines of pipe. If two lines are used they are spaced about 21 inches apart; if three lines are used, they are placed about 13 inches apart. The iron posts are spaced generally 8 feet center to center. The pipes are fixed at the bottom by anchoring the bases in the ledge or concrete for a depth of 9 inches, or else the bottoms are set in a cast iron flange which is bolted to the ledge or masonry. The cost of gas pipe railing, erected, is about 75 cents per linear foot.

Concrete Rails. Concrete guard rails, as described in the 1910 New York State Highway Commission Report, consist of concrete rails set on top of concrete posts. The rails are built with an inverted rectangular trough section and are 8 feet long

by 7 inches deep by 9 inches wide. Each rail is fitted with three cross diaphragms connecting the sides and top, one being placed at the center and one 4 inches back from each end. The rails are reinforced with four ⅜-inch square rods, one being placed at each corner, and the diaphragms are reinforced with a loop of the same size rod. The rails are set 3 feet 2 inches above the ground on concrete posts. The sides of the adjacent rails, with their respective end diaphragms, form a socket into which the top of the post fits. The posts are 6 feet 6 inches long and 5 inches by 7 inches square and are reinforced with a ⅜-inch square rod in each corner. The posts are set 3 feet 6 inches in the ground. The cost of concrete guard rails is estimated to be about 50 cents per linear foot and the maintenance cost is negligible.

Parapet Walls. On masonry bridges and retaining walls, parapet walls that serve as guard rails are constructed above the level of the roadway. The walls are a part of the rest of the structure and are built of the same material. This type of construction generally gives the structure a better appearance than any of the types of guard rails described above. It is also much the stronger and involves no maintenance costs. These advantages render the construction of parapet walls advisable where masonry bridges and retaining walls are being constructed.

CHAPTER XXVII

ECONOMICS, ADMINISTRATION, AND LEGISLATION

Economics

Active interest in the improvement of highways outside of built up districts may be said to have been under way in the United States for the past twenty-five years. During this period marked progress has been made in the methods of construction. Very little consideration, however, has been given to the economic phase of the problem. The different countries of Europe have developed excellent systems of highways, but it has been a gradual development based in part on the roads laid out and constructed by the rulers of the Roman Empire. A well connected system of highways played an important part in the development of some of the European countries, and it is not surprising, therefore, to find that as a general rule the highway systems of these countries are much further developed than is the case in the United States. At the present time in this country only about ten percent of the total of over two million miles of highways outside built up districts have been improved. It should be remembered, however, that in the development of the United States the railroads have played a very important part and that the area of this country is almost as large as that of all Europe. If the railroads had not been built so extensively, the demand for a comprehensive system of highways would have been more urgent. The problem in many European countries is mainly one of maintenance, whereas in this country it is one of construction and maintenance.

Methods of Financing. The construction and maintenance of highways involve the expenditure of large sums of money which must eventually be paid by the people. In business, unless the capital invested is protected by available assets and

unless it has an earning capacity, the investment is not considered a desirable one. To apply this criterion to the expenditure of money for highway construction is rather difficult, but the same underlying principle should be kept in mind. It is practically impossible to state the value of good roads in dollars, although statisticians have frequently attempted to show the saving that would result in the cost of hauling various products over improved surfaces. Such figures may be very misleading, since they are based frequently on data of a meager nature. The return for the capital invested will therefore have to be summed up from the standpoint of the advantages accruing. Among the advantages resulting from the construction of highways may be cited the following: a decrease in the cost of haul, the development of communities and consequent increase in land values, and the development of a community both intellectually and socially due to the facilitation of intercommunication and communication with the large centers. It is apparent that many of these advantages cannot be estimated on a money basis. Although the surfacing will wear out in time, the advantages resulting from the original improvement are permanent, and under proper methods of financing the cost would not be considered out of proportion to the benefits derived. The systems of financing the construction of roads and streets in the United States may be discussed under the following heads:

1. Labor tax.
2. Direct taxation.
3. Direct appropriation.
4. Bond issues.
5. Private subscription.

Labor Tax System. The labor tax system permits the payment of road taxes in labor instead of cash. This system was extensively used in the United States in the development of highways outside of built up districts up to the early nineties. It is rapidly being abolished, as in 1904 only one-fourth of the total of $80,000,000 spent on good roads was paid for in this manner. Little good can be expected from such a system since interest and earnestness of effort are generally lacking. The work

is usually done at times which suit the convenience of those that perform it rather than at times which would be advantageous from the standpoint of the improvement of the highways. Of course work done by this method is better than none at all, but it is realized that the expenditure of an equivalent sum of money under intelligent administration will produce better and more far reaching results. There are instances where results accomplished by this method have been very satisfactory, as for example the excellent work done with road drags on the highways in different parts of the country, particularly in connection with the maintenance of earth roads.

Direct Taxation. In many rural communities a certain part of the general tax is assessed as a highway tax to be used both in the construction and maintenance of the highways. It is generally, however, of such small amount that very little new construction can be accomplished. In order to further the construction of new highways, several States levy a tax for this purpose on the abutting property, which pays in part for the cost of new construction. Such a system is thought to be an equitable one in some localities. In districts where there are large areas between the highways the amount of tax is varied, depending upon the distance of the property from the highway. One advantage of the direct tax is that future indebtedness is never to be feared. The paving work in most of the cities of the United States is carried on generally by some form of special assessment, which is the direct tax system. The practice varies in different cities. While in some cases the entire cost of grading is paid by the city, there are a few instances where the city pays a certain percent of this cost. As a general rule, however, the entire cost for this work is assessed against the abutting property. The same general scheme is also carried out in laying the original paving and in repaving work. An examination of Table* No. 34 will show the practice as followed in several American cities.

The amount of assessment is based on the frontage of the property on the street, the total area, or a combination of the frontage

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* See Transactions, Am. Soc. C. E., Vol. XXXVIII, pages 336–342.

TABLE No. 34

Apportionment of Cost of Pavements in Fifty Cities

Locality			Grading Percent Paid by		Original Paving Percent Paid by		Repaving Percent Paid by	
Ref. No.	State	City	Property	City	Property	City	Property	City
1.	Alabama	Montgomery	50	50	50	50	50	50
2.	Arkansas	Little Rock	100	...	100	...	100	...
3.	California	San Francisco	100	...	100	...	...	100
4.	Connecticut	Hartford	...	100	67	33	...	100
5.	"	New Haven	...	100	*a*	...	*b*	...
6.	Dist. of Colum.	Washington	...	100	...	100	...	100
7.	Delaware	Wilmington	...	100	...	100	...	100
8.	Florida	Jacksonville	50	50	50	50	50	50
9.	Georgia	Atlanta	...	100	67	33	67	33
10.	"	Augusta	50	50	50	50	50	50
11.	Illinois	Peoria	100	...	100	...	100	...
12.	Indiana	Indianapolis	100	*d*	100	*d*	100	*d*
13.	Iowa	Burlington	...	100	100	*c*	...	100
14.	Kansas	Topeka	...	100	100	...	100	...
15.	Kentucky	Louisville	100	...	100	...	...	100
16.	Louisiana	New Orleans	75	25	75	25	75	25
17.	Maine	Portland	...	100	...	100	...	100
18.	Maryland	Baltimore	100	...	100	...	...	100
19.	Massachusetts	Lowell	100	...	...	100	...	100
20.	"	Springfield	...	100	...	100	...	100
21.	"	Worcester	100	...	...	100	...	100
22.	Michigan	Detroit	100	*c*	100	*c*	100	*c*
23.	Minnesota	Minneapolis	...	100	100	*c*	100	*c*
24.	"	St. Paul	100	...	100	...	100	...
25.	Missouri	Kansas City	100	...	100	...	100	...
26.	"	St. Louis	...	100	100	...	100	...
27.	Nebraska	Omaha	50	50	100	*c*	100	*c*
28.	New Hmpshre	Manchester	...	100	...	100	...	100
29.	New Jersey	Newark	100	...	100	...	100	...
30.	"	Paterson	100	...	100	...	...	100
31.	New York	Albany	100	*d*	100	*d*	100	*d*
32.	"	Brooklyn	100	...	100	...	50	50
33.	"	Buffalo	100	...	100	...	100	...
34.	"	New York	100	...	100	...	...	100
35.	"	Rochester	100	...	100	...	100	...
36.	"	Syracuse	100	...	100	...	100	...
37.	Ohio	Cincinnati	98	2*c*	98	2*c*	98	2*c*
38.	"	Dayton	100	*c*	100	*c*	100	*c*
39.	Oregon	Portland	100	...	100	...	100	...
40.	Pennsylvania	Harrisburg	100	...	100	...	100	...
41.	"	Philadelphia	...	100	100	...	...	100
42.	"	Scranton	100	...	100	...	50	50
43.	Rhode Island	Providence	100	...	...	100	...	100
44.	South Carolina	Charleston	...	100	...	100	...	100
45.	South Dakota	Sioux Falls	100	*c*	100	*c*	100	*c*
46.	Tennessee	Nashville	...	100	...	100	...	100
47.	Utah	Salt Lake	50	50*c*	100	*c*	100	*c*
48.	Virginia	Richmond	...	100	...	100	...	100
49.	Washington	Seattle	100	...	100	...	100	...
50.	Wisconsin	Milwaukee	100	*c*	100	*c*	...	100

a 1 sq. yd. for each front foot; city remainder. *b* 3½ sq. ft. for each front foot; city remainder. *c* City pays for street intersections. *d* City does not pay for street intersections.

and the area. The frontage rule is more commonly used than either of the others. In some cases the amount assessed is due on completion of the work. In others, however, the amount is paid in several equal annual installments, deferred payments bearing interest. The charter of New York City was amended in 1910, with reference to the paving and repaving of streets and the method of payment therefor, to read as follows:

"Street pavements shall be divided into two classes, namely: Class 'A,' or permanent pavements, and Class 'B,' or preliminary pavements. Class 'A' shall include all pavements of sheet asphalt, asphalt block, wood block, granite block, or other materials that shall, from time to time, be designated for this class by the Board of Estimate and Apportionment. Class 'B' shall include all pavements of bituminous macadam and such other pavements, that shall from time to time be designated for this class by the Board of Estimate and Apportionment. No street, or portion thereof, that shall have been paved with class 'A' pavement shall be repaved at the expense of the adjoining property-owners, unless a majority of the owners of the property on the line of the proposed improvement shall petition for such repaving at their expense by assessment.

"Whenever a street paved with class 'B' pavement shall be repaved, the repaving shall be done with class 'A' pavement, unless owners of property on the line of the proposed improvement petition the local board having jurisdiction for a second class 'B' pavement, to be laid at the expense, by assessment, of the adjoining property-owners, and in such event second class 'B' pavement shall be laid if said local board so orders, and the Board of Estimate and Apportionment consents. Whenever a class 'A' pavement shall be laid to replace a class 'B' pavement that has been laid at the expense of the property-owners by assessment there shall be deducted from the cost of such improvement the cost of the class 'B' pavement, and the difference shall be paid by assessment upon the adjoining property, and the amount equal to the cost of said class 'B' pavement shall be borne and paid by the city. But in no case shall the cost of a second or additional class 'B' pavement be so deducted from the

amount to be assessed for the laying of a permanent or class 'A' pavement.

"The class of the original pavement of any street shall in all cases be determined by the local board having jurisdiction and the Board of Estimate and Apportionment."

Another form of direct taxation is the licensing of motor vehicles. The money received in license fees for both vehicles and operators and the money received from penalties and fines imposed for non-observance of the laws as a rule is paid into the state treasuries to be used in furthering the road work throughout the states. In 1910 the revenue collected in New York State from this source amounted to $700,000.

Direct Appropriation. When payment for highway improvement is made from the general taxes of a community, the expense is borne by all the people residing therein. A large amount of the state highway work is paid for on this basis. In many countries, municipalities, and towns an amount sufficient to cover the cost of the highway improvement is made an item of the annual budget.

Bond Issues. Due to the large sums of money involved, where any great amount of construction is contemplated, the revenue available from the general taxes will not meet the expense of the improvement. In such cases it has become common procedure to issue bonds, bearing interest from 2½ to 4 percent, which are redeemable at different periods depending upon the work to be done. The amount of bonds issued should never be out of proportion to the taxable wealth of the corporate body issuing them. The yearly cost of the bonds will be the sum of the amount which will have to be paid out in interest and the amount which will have to be set aside as a sinking fund to redeem the bonds. The issuance of bonds renders a large sum of money available for immediate use and extends the repayment over a long period of years.

It is obvious that monies paid from the proceeds of bond issues are nothing more than direct appropriations, the cost of which is borne by all. Live current topics of discussion are the following economic problems: first, the advisability of a

community incurring a large indebtedness for purposes of highway improvement and, second, the equity of the apportionment of the expense. If the term of the bonds is made so long that the highways are worn out before the bonds are redeemed and no provision is made either for the maintenance of the highways or for the redemption of the bonds, a very unfortunate situation arises. To illustrate this point the following case was cited by Clifford Richardson, M. Am. Soc. C. E.:

"It appears from the Report of the Register of Deeds of the County of Mecklenberg, N. C., that in 1870 it issued bonds for $300,000 to run for twenty years bearing 6 percent interest. For twenty years the community paid annually $18,000 interest on this loan. When the bonds became due in 1890, $360,000 interest had been paid, but no provision had been made for retiring the principal. It was therefore necessary to issue $300,000 in bonds payable after another thirty years, and at a like rate of interest, to take up the first series. By 1920, when these bonds become due, $900,000 in interest will have been paid thereon, and the county will still owe the amount borrowed." Richardson further states that "as the life of a well constructed road may be looked upon as being between ten and fifteen years, a community which issues bonds of this type (to run for ten to fifteen years), with the proper provision for sinking fund, cannot be considered to have done anything unreasonable, especially in view of the fact that the improvement in the value of adjacent property by the construction of good roads and the consequent increase in its taxable value may more than meet the demands of the sinking fund and interest. The bonds would be paid for and the debt wiped out during the life of the road, and the cost of the latter would be the amount paid. There would be no further responsibility incurred.

"It would be very different, however, if bonds were issued for forty-one years, as in the case of one of the Provinces of the Dominion of Canada, and as has been proposed in a bill for the encouragement of road building in North Carolina, submitted to the legislature of that State. This bill provides

that bonds shall be issued by the State at 4 percent interest for a term of forty-one years. The money thus obtained shall be loaned to the various counties in the State for highway construction at an interest of 5 percent, 4 percent of which shall be devoted to payment of interest on the bonds and 1 percent devoted to a sinking fund, which would retire the bonds at maturity. On its face this is a satisfactory proposition for meeting indebtedness, but the viciousness lies in the fact that the roads' surfaces, which might be constructed with such funds, would have been worn out and have disappeared after not more than fifteen years. The State and counties would then have no roads and the original cost of constructing them would still be a debt extending for a period of twenty-six years. It would be again necessary to borrow money by bonds of the same description to build new roads."

Nelson P. Lewis, M. Am. Soc. C. E., in making a report to the Board of Estimate and Apportionment of New York City, said, "The term of bonds issued for repaving should be no longer than the probable life of the pavement, or still better, the funds for repaving should be included in the annual budget and the city's borrowing capacities reserved for other purposes."

It is quite usual to find that the state laws restrict the construction of state highways to those without the limits of the cities. Since the majority of the people live within the cities, the question is frequently raised as to the equity of forcing the residents within the city limits to bear a large proportion of the expense of constructing roads beyond the city limits. It should be remembered in this connection that at the present time, in order to meet modern traffic conditions, it is necessary to adopt types of construction which greatly increase the cost of the work. A study of the results of traffic censuses in several instances would indicate that a large percentage of the motor car traffic emanates from the cities. A system of improved highways leading from a city to the country districts tends to further the city's development and to increase certain business enterprises carried on within the city. The cities as well as the country districts are benefited both financially and socially, and it there-

fore does not seem unjust to apportion the burden among all the people.

Private Subscription. There are a few instances where roads have been built by private subscription. The largest undertaking of this kind is the Coleman du Pont road, now being constructed in Delaware. There have been several roads constructed throughout the country, however, by private capital as a business enterprise. These roads after construction were operated as toll roads, but at the present time most of them have been taken over by the States through which they pass and made into public highways.

Administration and Legislation

There is a marked difference between the systems of administration regulating highway improvement in Europe and the United States. In Europe the construction and maintenance of highways outside of the large cities in many instances is regulated and controlled by the national government, and where the government does not build national highways, a national board may exist having control in certain matters. Another very pertinent fact is that European administration is in the hands of experienced engineers. In the United States there is no national system of highways, each State acting independently in this matter. Within many states the same lack of centralization of authority is found in the highway work undertaken by the various counties and towns. The administration of the state, county, and town highways is vested in boards or commissions composed of several men, or else the authority rests in the hands of one man. Unfortunately in the majority of instances these men are not engineers and, although it is necessary to employ an engineering organization to carry out the work, some of the work is not done on sound engineering principles, due to interference by the lay bodies. Moreover, a great deal of the money spent for construction and maintenance is wasted because of the lack of centralization of control. The different systems of a few of the principal countries of the

world will be described which are typical illustrations of general practice.

France. In France the highways are classified as routes nationales (national roads), routes départementales (departmental roads), and chemins vicinaux (vicinal roads). The chemins vicinaux are divided into several subsidiary classes; chemins vicinaux de grande communication (roads of great importance), chemins vicinaux d'intêret commun (roads of common interest), and chemins vicinaux ordinaire (roads of little importance). Jean de Pulligny, M. Am. Soc. C. E., states that,

"For many years the tendency in all Départements has been to have only one class of roads, the chemins de grande communication. No more chemins d'intêret commun are created and every year some routes départementales drop from the official lists and they are thence counted as chemins de grande communication. The length of the routes départementales has thus fallen from 29,500 miles in the year 1869 to 8,100 at the present time. On January 1, 1911, the road mileage in France was as follows: Routes nationales 24,000 miles, routes départementales 8,100 miles, chemins vicinaux 395,700 miles."

All of the routes nationales are constructed and maintained by the central government under the direction of the Département National des Ponts et Chaussées, the organization of which is as follows: The inspecteurs généraux, all of whom must reside in Paris, are of two grades. Those of the first grade form a permanent board of which the ministre de travaux publics is the nominal president. The board is actually presided over by a vice-president, an inspecteur-général who is appointed by the ministre. This permanent board is augmented by half of the inspecteurs généraux of the second class, each half serving six months. The board has direct control of all the work of the Département des Ponts et Chaussées in France. Besides the care of the routes nationales the Département has under its supervision all improvements in connection with the bridges, rivers, canals, harbor improvements, the control of the railroads, and attached services in the colonies.

The board assigns inspecteurs généraux of the second class to special fields of inspection covering the work of several ingénieurs-en-chef and may in very important cases designate an inspecteur-général of the first class. The ingénieurs-en-chef who have charge of several lines of work may thus be subject to orders from a number of inspecteurs généraux. The remainder of the organization comprises ingénieurs ordinaires, sous ingénieurs, conducteurs principaux, conducteurs, commis principaux, commis and commis stagiaires. The title ingénieur ordinaire is conferred on men at the time of their graduation from L'Ecole Nationale des Ponts et Chaussées. Sous-ingénieurs, conducteurs, and commis are not graduates of the national school and are not eligible to the grade of ingénieur des Ponts et Chaussées.

Pulligny also says that "France is divided into eighty-six territorial units called Départements. Each French Département is also a unit for several public services and it is a political unit. It has a governor, called a préfet, appointed by the central government, and an elective body called conseil général.

"All of the chemins vicinaux within a Département are managed by the préfet of that Département and the necessary expenditures are appropriated by the conseil général. The direct charge of the work is in the hands of a centralized body of competent technical men. In about one-half of the Départements the work is intrusted by the conseils généraux to the body of government engineers who are graduates of L'Ecole Nationale des Ponts et Chaussées. In forty-six of the French Départements special technical bodies under a chief road engineer have been organized to look after the work.

"Each Département is divided into four or five political districts headed by a sous préfet and called an arrondissement. In each capital of these districts resides a district road engineer who works under the direction of the chief road engineer, having charge of all the chemins vicinaux of the arrondissement. Each arrondissement is divided into four or five judicial districts, named cantons, having also their small capitals. An assistant road engineer acting under the direction of the district road

engineer looks after all the chemins vicinaux in the canton. Finally all the roads in the canton are divided into sections a few miles long and on each of these sections works constantly the celebrated French cantonnier or road patrolman, whom all the motorists have noticed with his pickaxe, shovel, broom, and wheelbarrow. These cantonniers are under the orders of the assistant road engineer. A few of them who have a shorter section look after the work of their neighbors and are called chefs cantonniers.

"The cantonniers are simple laborers, generally of agricultural training, and no special knowledge is required of them to enter the service. They are only expected to act with respectable behavior, to be able to read and write and to be steady, trustworthy workers. All the members of the road service from the patrolmen to the chief engineer work under a civil service law. When they have once entered the service they can only be dismissed in case of serious misbehavior. They are promoted to a better pay at regular intervals and when they retire after thirty years of work, they receive an old age pension. The district engineers are generally chosen from the most able and experienced assistant engineers who have been in the service for many years. The chief engineer of the Département may have been previously a district engineer, but it is not obligatory. In some cases he formerly was a civil engineer, a graduate from one of our principal schools or an architect or an Ingénieur des Ponts et Chaussées."

Germany. The highways of Germany are under the control of the different states forming the Empire. The various provinces within the states receive state aid for the construction of main roads. In Prussia the work is generally supervised by the Minister of Public Works. The direct administration, however, is in the hands of the provincial authorities, who in turn can transfer authority to smaller communal bodies such as districts and parishes. In Saxony the state is divided into four divisions, each one of which is supervised by an executive officer of the Department of the Interior. The four divisions are further subdivided into twenty-seven districts, the work in each district being administered by important executive officers. The actual

work of construction and maintenance throughout the Empire is in the hands of carefully trained technical men.

Great Britain. In Great Britain two classes of highways are generally recognized, namely, main and district roads. The classification, however, is not very satisfactory, as there are main roads, which carry only local traffic, and in some parts there are principal trunk roads, which are classified as district roads. Previous to 1909 the highway administration was in the hands of county councils, which had the care of the main or county roads, and district councils, urban and rural, which had the care of the remainder of the public highways. The cost of the work was paid for by the taxpayers residing in the counties and districts, assisted by grants from the Imperial Exchequer. One very admirable feature of the British system of administration is the power given the Local Government Board relative to the borrowing capacity of a county or district council. Before either can borrow money for highway improvement it must satisfy the following regulations of the Local Government Board:

The sum borrowed shall not exceed at any time, including all outstanding loans, the assessable value for two years of the district. Where it exceeds the assessable value for one year, the Board does not give its sanction until one of its inspectors has held a local inquiry. The repayment of the money borrowed must be made within a certain time fixed by the length of life of the proposed work.

In 1909 an act was passed by Parliament creating a Road Board composed of five men, which was changed a year later to eight. This Board was appointed for the purpose of improving the facilities for highway traffic in the United Kingdom. The Road Board, with the approval of the Treasury, has the power to make advances to county councils and other highway authorities for the construction and maintenance of roads. Any advances may be either by way of loan or by way of grant or upon such terms and subject to such conditions as the Board may impose. Before the approval of the Treasury is given to the construction decided upon by the Road Board, the Local Government Board is consulted and notices are sent to every highway

authority in the area of which any part of the proposed road may be situated, and a public hearing is held at which the construction of the road is considered from every standpoint.

Switzerland. The highways in Switzerland come under the direct supervision of the authorities of the separate Cantons. The State exercises no control over the highways except that by reason of the fact that it assists the Cantons financially to some extent it may impose certain regulations before rendering such assistance. The engineers in direct charge of the work must be technically trained men.

Other European Countries. In Spain, Italy, Belgium, Austria, and Portugal the scheme of administration of highway construction is very similar in each case to that of France.

United States. In the United States there is no national system of highways, although many bills proposing national participation of the government in the construction of highways have been brought before Congress, but never passed.

The Office of Public Roads, which is a branch of the Department of Agriculture, is maintained by the Government for the purpose of the accumulation and dissemination of knowledge with reference to highways. The office is equipped with laboratories for testing certain kinds of road materials. It also supervises the construction of experimental roads in various parts of the country with a view of showing the different localities what can be done with the materials.

There are many states, however, which have adopted a system of state highways that are paid for either wholly or in part by the State, the money being frequently raised by issuing bonds. Highway work undertaken by the various counties and towns within the states is usually carried out without any control on the part of the state authorities unless financial aid has been rendered by the State. The administration of the work in the various states is usually vested in a commission, a commissioner, or a state engineer appointed in many cases by the Governor of the state, subject to the approval of the state legislature. Unfortunately politics play too important a part in these appointments and seriously interfere with the establishment of an

efficient organization. Several instances might be cited where the personnel of the commission and its attendant engineering organization have been entirely changed mainly for political reasons.

New Jersey was the first state in the United States to adopt a policy of state aid for the construction of highways. The New Jersey State Highway Department was established in 1891. Some form of state aid has been adopted by the different states from time to time up to the present until only eleven out of the forty-eight states in the Union have not yet enacted laws for this purpose. State aid is not always given in the form of money, and there are several states in which the aid comprises only the furnishing of engineering advice and assistance. Only a very brief resumé of highway legislation as enacted by a few states will be given.

Alabama. The State Highway Commission consists of the Professor of Civil Engineering at the Alabama Polytechnic Institute, the State Geologist, and three civilians to be appointed by the Governor. The Commission appoints a State Highway Engineer, whose duties are to prepare road maps of the state and to give engineering advice and assistance. The annual appropriation is $154,000, taken from the convict fund. This fund, minus the expenses of the Commission, is divided equally among the different counties of the State, but before any county can obtain its allotment it must appropriate a like sum. The work within the counties is in the hands of a court of county commissioners, who divide the counties into a number of road precincts, each one of which has its own road overseer.

California. The Department of Engineering consists of an advisory board composed of the Governor, who acts as ex-officio chairman, the State Engineer, the General Superintendent of State Hospitals, the Chairman of the State Board of Harbor Commissioners of San Francisco, and three members appointed by the Governor. A highway engineer is also appointed by the Governor. The California State Highway Commission is composed of a committee of three from this engineering department and the highway engineer reports to this Commission. An

$18,000,000 bond issue was made available in 1909 for the construction of a system of state highways. The counties are required to pay 4 percent interest on the amount of the bond issue spent within the county minus a sum depending upon the relation between the bonds matured and the bonds outstanding. Several roads in districts which are too poor to pay for them are constructed and maintained by state appropriations.

Connecticut. A State Highway Commissioner is appointed by the Governor with the approval of the Senate. The Highway Commissioner has very complete authority with reference to the construction and maintenance of state aid roads. State aid may be obtained by any town upon written application of the selectmen of that town. Towns which have a valuation of over $1,250,000 are entitled to receive from the State three-fourths of the cost of construction of roads under provision of the state aid act, and towns under $1,250,000 valuation receive seven-eighths of the cost.

Illinois. The Highway Commission consists of three persons appointed by the Governor, who serve without pay. A State Engineer is appointed by the Commission. The Commission acts in an advisory capacity and may be consulted by any of the county, city, village, or township highway officials. An appropriation of $65,000 per year is made for the support of the work of the Commission, which work includes the preparation of road and bridge plans, estimates, collection of statistics, and experimental work. Convicts are used to manufacture various road materials and machines which are furnished free to the various counties applying for them with the proviso that they be used subject to the approval of the Commission.

Maryland. From 1898 to 1904 engineering advice was furnished to the various road officials throughout the state by the Maryland Geological and Economic Survey which received an annual appropriation from the State of $10,000 for this purpose. In 1904 the State voted to appropriate $200,000 annually for state aid work, the money to be spent under the direction of the Geological and Economic Survey. Two bond issues have been passed, one for $5,000,000 in 1908 and one for $1,000,000

in 1910, for the construction of state roads. Since June 1, 1910, the work has been done under a State Roads Commission consisting of the Governor, ex-officio, two members appointed by him from the State Geological and Economic Survey, and three civilian members also appointed by him. The work of construction and maintenance is carried out by an engineering organization under a chief engineer. The bond issues are for the construction and maintenance of roads, the cost of which is entirely borne by the State. State aid roads are also constructed in the various counties, the cost being shared equally by the county and the State, the work being done under state supervision. The maintenance of state aid roads, however, is carried out by the county authorities with state supervision.

Massachusetts. The Massachusetts Highway Commission was formed in 1893 and consists of three members appointed by the Governor. Appropriations for the construction of state highways have been made since 1894. The county in which the state highway is located pays 25 percent of the cost of construction. A sum not exceeding 15 percent of the amount appropriated by the State may be used in the construction of town roads as follows: 5 percent in towns having a valuation of less than $1,000,000, the town making no contribution; 5 percent in towns having a valuation of less than $1,000,000, the town contributing an equal amount; 5 percent in towns having a valuation of more than $1,000,000, the town contributing a like amount. Roads declared state highways are maintained at the expense of the State after construction. Town roads built with state aid after construction are maintained by the towns. No state aid can be given until a petition from the governing body of the town, county, or city in which the road is located has been received and approved by the Commission.

New Jersey. The State Highway Commission consists of the Governor, President of the Senate, Speaker of the House of the Assembly, and a Commissioner of Public Roads appointed by the Governor. Under the Commissioner of Public Roads are a State Supervisor and two Assistant Supervisors. The State appropriates $400,000 annually for road construction, one-third

of the cost of any road being paid for by the State and two-thirds by the county. The surveys for a road are made by the county engineers at the expense of the county. Before receiving state aid, the plans and construction have to be approved by the Commissioner of Public Roads. County supervisors and county engineers are appointed by the Boards of Freeholders of the various counties.

New York. The State Commission of Highways of New York consists of the Commissioner, who is appointed by the Governor. The highways are divided into three classes: state, county, and town highways. The Commissioner appoints three Deputy Commissioners, the first deputy having charge of the plans, specifications, and execution of all contracts pertaining to the construction of state and county highways; the second deputy having charge of the maintenance of state and county highways; the third deputy having charge of the repair, improvement, and maintenance of town highways and bridges and county roads and bridges in the Indian reservation. The Commissioner also appoints nine division engineers who have charge of the construction and maintenance of the state and county highways in their respective divisions under the supervision of the deputy having jurisdiction thereof. District superintendents, resident engineers and inspectors are also appointed by the Commissioner. County superintendents are appointed by the boards of supervisors of the various counties, these superintendents being subject to the regulations of the Commissioner. Town superintendents, who are elected at the town meetings, report to the county superintendents. The cost of improving state highways is borne entirely by the State. The cost of improving county highways is distributed as follows: State, 50 percent; county, 35 percent; town, 15 percent. The appropriation made as state aid to towns for the construction of town highways is based upon the amount of taxes levied per mile of highway within the town. No town under this scheme, however, can receive an amount exceeding $25 per mile for the total mileage of the towns outside of the incorporated villages. The maintenance of the state and county highways is under the control of the Commission, an

annual appropriation being made to cover this expense. The towns, however, are required to pay $50 a year for each mile of state and county highways within their borders towards the expense of maintenance. New York ranks first in the amount of money raised for the construction of highways by the authorization of a $50,000,000 bond issue in 1906 and by the adoption of another $50,000,000 bond issue in 1912.

Ohio. A State Highway Commissioner is appointed by the Governor. The Commissioner appoints three Deputy Commissioners, one having charge of a bureau of construction, one having charge of a bureau of maintenance and repair, and one having charge of a bureau of bridges. The construction and maintenance of all improvements made with state aid are under the direction of the Commissioner. The cost of maintenance and repair is divided as follows: 25 percent by the State, 50 percent by the county, and 25 percent by the township.

Pennsylvania. A Highway Commissioner is appointed by the Governor. He also appoints two Deputy Commissioners and a Chief Engineer. The other members of the engineering force are appointed by the Commissioner. Since 1911 a sum of $4,000,000 has been appropriated, $3,000,000 of which is to be used for the maintenance, repair, and construction of state highways and for the payment of the State's share of the maintenance of state aid highways previously constructed. The remaining $1,000,000 is to be used in the permanent improvement of state aid highways. State highways are built and maintained at the sole expense of the State. A borough or incorporated town, however, is obliged to pay 50 percent of the cost of maintenance or reconstruction of a highway within its limits which has been declared a state highway and 100 percent if the highway was originally constructed as a state aid road with bricks or material other than water-bound macadam. State aid may be obtained by a county and township applying jointly or separately. In the first case the county pays 25 percent, the township 25 percent, and the State 50 percent of the cost of construction; in the second case, 50 percent of the cost is borne by the State and 50 percent by the county or township applying. Where the county

and township apply separately, 50 percent of the cost of maintenance is paid by the one applying and 50 percent by the State.

Rhode Island. A State Board of Public Roads composed of five civilians, one from each county in the state, was appointed by the Governor in 1902. The Board appoints an Engineer. Since 1902 several direct appropriations for the work of building state highways have been made by the State and $1,800,000 in bond issues have been authorized. A state highway having a width of improved surface of 14 feet is built and maintained entirely at the expense of the State. Should a wider road be desired the town through which the road passes pays for the extra width over 14 feet, the whole width, however, being maintained by the State. A state aid law has also been passed in which the State appropriates a sum equal to one-fifth of a sum raised by the town. The sum raised by the town must be in the way of an annual appropriation and must be equal to or more than a sum of 20 cents on each $100 of ratable property of the town. The town is also required to vote that the expenditure of this money shall be under the direction of the State Board and for the maintenance and repairs of highways and bridges other than state highways.

Administration in Cities. The administration of highways within the cities is usually controlled by the governing body of the city. In the United States the carrying out of the work is accomplished by three generla methods of administration, which may be well illustrated by a brief review of the practice in Boston, Providence, and St. Louis.

Boston. A chart, shown in Fig. 234, illustrates the difference in the old and new systems of administration in Boston. The old system was abandoned in favor of the new on account of the lack of co-operation between the departments of the City Engineer, the Water Commissioner, and the Superintendent of Streets. These departments acted practically independent of one another, which led to endless confusion and waste of money. In the new system it will be noted that the direct controlling officer is a Commissioner of Public Works, an engineer, who reports to the Mayor. Under this Commissioner are three

Deputy Commissioners, one having charge of the sewer and water division, one of the highway division, and one in charge of the bridges and ferries division. It is apparent that in this last

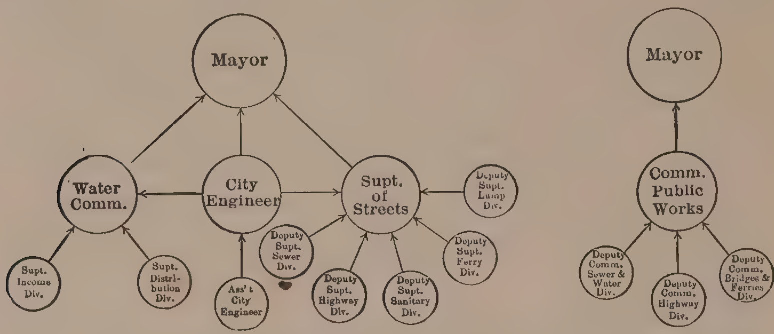

FIG. 234. Old and New Systems of Organization of Public Works Department, City of Boston.

arrangement the relations of the three divisions are controlled by one head, who can insist on co-operation and centralization of effort.

Providence. A Commissioner of Public Works is appointed by the City Government who directly controls the work of the engineering department. The City Engineer heads a department the several divisions of which, such as bridges, sewers, streets, and water works, are in charge of Assistant Engineers. The Commissioner of Public Works, who is not an engineer, has the final decision as to the expenditure of money appropriated. The City Engineer reports directly to the Commissioner as to methods of construction, which recommendations are usually carried out. The maintenance of streets, however, has been until recently practically without the control of the Engineering Department and in the hands of the Commissioner of Public Works. The system is much more efficient by having the maintenance work also controlled by the Engineering Department.

St. Louis. In this city a Commission, composed of engineers, supervises all public work, each branch being in charge of a member of the Commission. Each branch has its own complete organization and the work of all the branches is co-ordinated by

the Commission. Since the different members of the Commission co-operate with each other in their various lines of work through the medium of frequent meetings, the result is that all the public work is carried out with a minimum amount of delay and friction that would otherwise be of serious moment. Important meetings of the Commission are presided over by the Mayor.

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